

2004

COGNITIVE IMPACT OF INTERACTIVE MULTIMEDIA

Yanko F. Michea,
The University of Texas School of Health Information Sciences at Houston

Follow this and additional works at: https://digitalcommons.library.tmc.edu/uthshis_dissertations



Part of the [Medicine and Health Sciences Commons](#)

Recommended Citation

Michea,, Yanko F., "COGNITIVE IMPACT OF INTERACTIVE MULTIMEDIA" (2004). *UT SBMI Dissertations (Open Access)*. 7.

https://digitalcommons.library.tmc.edu/uthshis_dissertations/7

This is brought to you for free and open access by the School of Biomedical Informatics at DigitalCommons@TMC. It has been accepted for inclusion in UT SBMI Dissertations (Open Access) by an authorized administrator of DigitalCommons@TMC. For more information, please contact digitalcommons@library.tmc.edu.

Cognitive Impact of Interactive Multimedia

A

DISSERTATION

Presented to the Faculty of
The University of Texas
Health Science Center at Houston
School of Health Information Sciences
in Partial Fulfillment
of the Requirements

for the Degree of

Doctor of Philosophy

by

Yanko F. Michea, MD

Committee Members:

Cynthia L. Phelps, Ph.D.¹

Todd R. Johnson, Ph.D.¹

Jiajie Zhang, Ph.D.¹

¹The University of Texas Health Science Center at Houston, School of Health Information Sciences, Houston, Texas

Cognitive Impact of Interactive Multimedia

Introduction

Since the eighties, technology has gradually taken an increasingly important role in our culture. Educational institutions have invested significant amounts of resources into the integration of information technology across the wide diversity of tasks involved in the educational enterprise. The increased availability of increasingly powerful computers has supported the development of games, simulations and a variety of other multimedia applications with diverse degrees of educational success. One of the major inspirations for this dissertation projects was the lack of empirical evidence to understand or defend the selection of multimedia as educational strategy. The goal of this dissertation was to increase our knowledge about the use of these tools in health education, trying to find organizing principles to guide our development and evaluation of interactive multimedia for health education. Aware that this would be a major task for any researcher, the scope of the project was focused in the evaluation of a specific technology: Interactive Multimedia and a specific problem: Learning control rules in complex systems. This selection was critically important given the importance of understanding these kinds of rules in medicine (our understanding of normal and abnormal processes in human organisms is based in this kind of analysis), and because our understanding of the role of interaction as a cognitive tool is still very limited.

The manuscripts included in this dissertation have the goal of representing the steps and knowledge gained across this dissertation process. The first article, *Strategies for Multimedia in Health Education*, had two objectives: to present an overview of the latest experiences in health education using multimedia, and to propose a conceptual

framework based in Distributed Representations theory in order to explain and systematize the use of multimedia in this domain. The evidence presented in this article proves the enthusiasm and interest in the use of highly interactive multimedia in health education and at the same time, the lack of a solid theoretical framework capable of explaining the success or failure of these interventions. Distributed Representations offers such kind of theoretical framework that in coordination with learning and systems' theory should contribute to understand these issues.

The second manuscript “Multidimensional Design of Educational Multimedia” is a step forward in this process as it is dedicated to the explanation of the development framework developed during this dissertation. The development of educational instruments is an intrinsically multidimensional task, involving and integrating education, technology, and cognitive science. In this document we present framework integrating this dimensions, proposing at the same time concrete strategies to develop and assess the outcomes of the process.

The evaluation of this kind of cognitive tool, required evaluation strategies capable of measuring learning not only in its behavioral representation, the most traditional method to evaluate learning, but tools sensitive to changes in cognitive processes. Traditionally qualitative methodologies, like Think Aloud Protocol has been used to assess this type of change. New methods, based in the so called “conceptual proximity data” represent the quantitative alternative to this method. At the time of this project there was not enough information relating the results offered by both methodologies. In order to bridge this gap, we developed a within subject comparison of conceptual models in order to compare and correlate these models. The results of this

experiment supported the hypothesis that both models are correlated and that the quantitative model was a reliable method to derive conceptual models.

The final step in this project was to assess the effect of Interactive Multimedia in learning. The results of this research are described in the article “Cognitive Impact of Interactive Multimedia: Comparing Impact of Diverse Representational Strategies”. The intervention was designed to evaluate how distinctively Interactive Multimedia was in learning the control rules of a system. The intervention was controlled against a static representation, and a video presentation of the content. The evaluation involved traditional assessment (multiple choice questionnaire), and a conceptual proximity evaluation (Pathfinder Network). The results of the study support the hypothesis that Interactive Multimedia has a greater impact in learning these concepts. The study is limited by the number of participants, and further research is going to be required to assess the impact in conceptual maps changes, as the results of the Pathfinder Network evaluation were not conclusive.

The final pages of this document discuss the most relevant conclusions of this process, and also outline a research agenda for the development of future research in this area.

Running head: STRATEGIES FOR MULTIMEDIA IN HEALTH EDUCATION

Strategies for Multimedia in Health Education

Yanko F. Michea, MD

School of Health Information Sciences

The University of Texas Health Science Center at Houston

Abstract

Technology has been gradually introduced in health education. One of the most attractive features of this technology-based education is the use of multimedia. In this article we explore the research evidence about the role that multimedia is playing in education. From that analysis we describe the most relevant features of this technology to prepare a common ground of discussion about the evaluation of its impact on educational outcomes. As part of this analysis, we organize current research evidence on the use of technology in medical education, distinguishing diverse variables involved in the process, like knowledge (declarative, procedural), learner characteristics, curricular scenario, etc. This article presents an overview of the Distributed Representations theory and its relationship with research on educational outcomes and multimedia. Next we discuss the relationship between media and diverse learning theories, proposing a theory based taxonomy for educational multimedia.

Strategies for Multimedia in Health Education

Is Multimedia Changing Health Education?

In recent publications, it has been suggested that education is slowly shifting from *Industrial Era* mass production paradigms towards a more personal, tailored *Information Era* paradigm (Reigeluth, 1999). The explosive increase of available information has fostered the development of evidence based medicine and also changes in educational orientation from the traditional emphasis in rote memorization towards a process comprehension or meaningful learning (Michael, 2001). Nowadays, the volume of information available exceeds the learners' memorization capabilities, transforming successful learners in skilled information navigators and integrators, shifting the focus from rote learning towards holistic comprehension of dynamic relationships and processes. In this scenario, technology should play a role supporting distribution and access to information and education. More importantly, technology has the capacity to support new education strategies. This development effort has been fostered by the increasing academic demands and fast development of informatics and telecommunications. Unfortunately, the results of the evaluation of these technology based tools and strategies are diverse and hard to integrate and use in non-experimental educational practice. The purpose of this manuscript is to offer an overview of the evaluation of multimedia in health education, from a technical, educational and cognitive standpoint. Understanding the current state of research will help us to guide our educational efforts, and to outline future research needs.

The exponential increase of medical knowledge requires educators to use new learning strategies and tools (Daetwyler, 2003). For health educators, defining best-practice principles for the selection or design of educational multimedia is an important task (Maleck et al., 2001). The evaluation of multimedia in education shows promising results even though there are still many inconsistencies in the results achieved (Letterie, 2003; Liao, 1998; Olson & Wisher, 2002). Multiple variables have been associated with these inconsistencies: inadequate use of learning theory, methodological flaws, inconsistent outcomes, inadequate development and evaluation frameworks, usability and human factors issues, etc. Further efforts must be made in order to develop an upper level framework to help us to understand these disparate outcomes and to effectively evaluate and apply technology in health education. The evaluation of the educational impact of technology is not only an academic research exercise, but an important educational and economic need. A recent report (Adkins, 2002) estimated that 10.3 billion dollars were invested in e-learning the year 2002, and that 44 billion dollars should be spent in e-learning for higher education over the following ten years. The determination of the best educational strategies for the use of multimedia in education is a prerequisite for a cost-effective use of these tools on a global scale.

The comprehension of the underlying processes and variables that improve learning efficacy is critical for the improved use of technology in education. Educational multimedia development requires the integration of knowledge from multiple disciplines like information science, technology, education, instructional design, cognitive science, etc. The development and evaluation of these applications has been marked by the influence of each one of these disciplines. The complexity and variability of research

results is also associated with the theoretical and methodological differences between these diverse disciplines, and also to the lack of a shared taxonomy to help us to compare products and results. The analysis of the literature must be aware of these issues in order to understand diverse educational outcomes.

In this manuscript we are going to analyze the major trends in evaluation of educational multimedia. The analysis will start with a definition and analysis of the characteristics of multimedia, following with a review of the evaluation of multimedia in health education and an overview of the cognitive issues related with multimedia and learning for health education. We believe that each one of these domains represents different layers of complexity, and that the integration of these multiple layers is key for the understanding of the current state and future of educational multimedia.

What is Multimedia?

The early monochromatic screens and command based interfaces have been replaced with increasingly interactive and visually compelling displays, generating expectation about the graphical possibilities of these artifacts. The buzzword “multimedia” was a phenomenon that appeared in the mid-eighties to identify computer systems and applications capable of reproducing not only text and pictures, but also video, animation, and sound. The development of increasingly good sound and video hardware allowed the development of increasingly rich applications. During the last ten years, the improved processing power of personal computers has also fostered the development of increased interactivity and computer “intelligence”. Educational applications have evolved from text based page turners to rich interactive applications. It

is remarkable how this fast evolution has generated an incredible diversity of products under the umbrella of “multimedia”, ranging from linearly interactive presentations to complex simulations. What is common to multimedia is the use of more than one kind of representation to convey some content message, usually with some degree of user control. Even though our common perception is that multimedia software implies the combination of multiple sensory channels, most of the time it is just the combination of multiple visual representations for the same content.

Multimedia has evolved from static hyperlinked text to a diverse arsenal of images and animations. Each visual element represents a concrete or abstract concept with a diverse degree of fidelity with the original object/idea represented. High resolution pictures of a tumor cell could be a good example of a high fidelity representation, while a simple line diagram of the same cell could be a low fidelity example.

Visual media can also be categorized regarding to its animation characteristics. An animation is basically a representation of changes over time. These changes can be changes in spatial relationships, or changes in the characteristics of the objects themselves. The concept of fidelity of the representation also applies here; a low fidelity animation can represent changes as a static series of images triggered by user interaction, while a high definition representation would be a full video (30 frames per second), pictographic representation of the same process.

The appropriateness of one representation or the other will depend on the learning task at hand. For instance, if you want to represent a kidney in a way that will allow a student to recognize almost any kidney, then a general description of the organ with a

simple drawing should suffice. On the other hand, higher fidelity images are going to be needed for recognition of specific features or to make decisions based in a specific scenario.

Compared with visual, aural representations, like descriptive sounds, speech and music, are harder of systematize. Current taxonomies account just for basic aspects of this media, without much discussion of the relationship between content fidelity and learning, or about the cognitive processes triggered by them. There is limited for multiple reasons besides the theoretical, some of them strictly practical (the institutional use of sound in computer labs is restricted for the availability of hardware or headphones), accessibility issues, and characteristics of the contents in the health domain. Further research is going to be needed to take full advantage of this media, especially given its relevancy to improve accessibility for visually impaired learners.

Tactile representations are emerging since the last decade given the increased availability of haptic systems, even though the cost of this type of equipment is still an important deterrent for their mass application in education. In spite of these limitations, there have been multiple experiences of simulations for skills training in surgery, endoscopy, venous puncture, etc. Other sensory channels, like smell or taste are much more limited and their use in multimedia education remains largely unexplored.

Most multimedia applications are actually composed of a diverse combination of each one of these media elements. In order to navigate, modify or generate the contents of the application, the learner needs to interact with the software interface. This interaction can be simple as in the case of a linear navigation through a page turner, or complex as in the case of complex simulations. There is a whole range of degrees of

interaction in between, as well as variable combinations of interaction styles mixed inside an application.

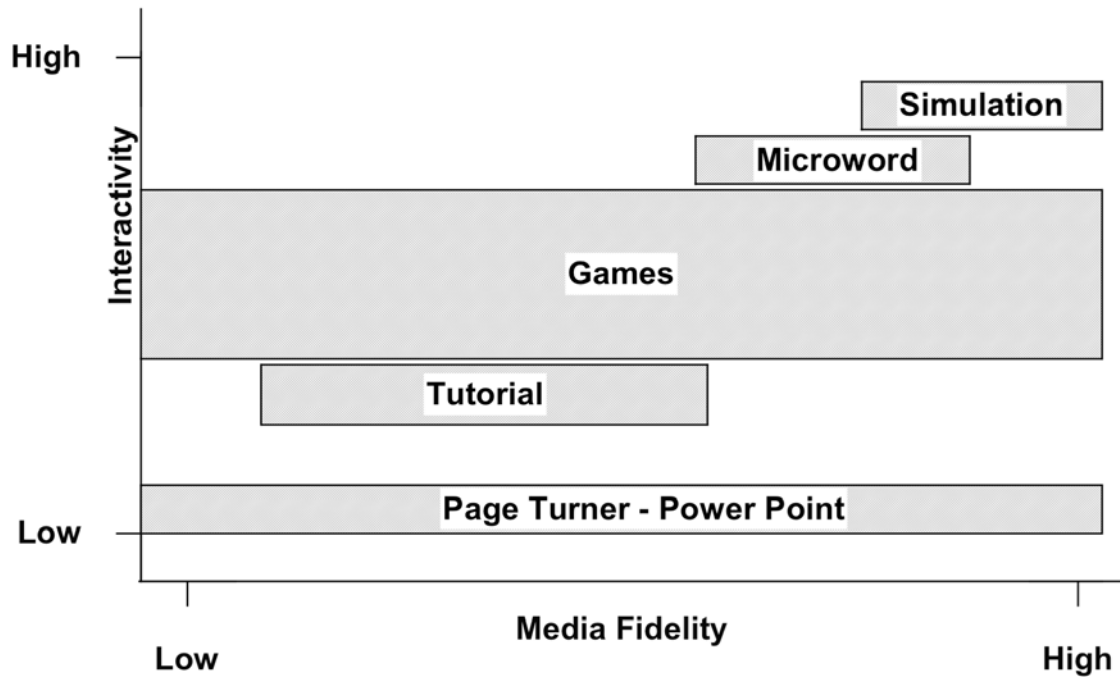


Figure 1

Interactivity and fidelity in diverse media types.

The combination of media, and interaction exists in order to represent and support learning of some content. This content will vary depending on curricular and pedagogical decisions. A multimedia application can contain a single topic, like the cardiac cycle, or a much complex representation of the physiology of the cardiovascular system. From a

technology standpoint, a multimedia application is the product of the combination of content, media representation and interaction design.

One of the major problems by the time research needs to be analyzed in order to determine the best solution for any educational problem is not only the diversity of multimedia applications that can be designed for any educational purpose, but also the lack of information about the characteristics of the application that was evaluated in each particular scenario. The selection of a particular application's design should be based on research outcomes measuring learning efficacy of different designs. However, this research is scattered and incomplete, making difficult to relate their specific design issues to educational outcomes because of the products are multifactorial.

Multimedia and Educational Outcomes

Current evaluation of a variety of programs with a diverse combination of animation and rich interaction indicates a variable degree of learning success (Blankenship & Dansereau, 2000; ChanLin, 1998; Liao, 1998; Mergendoller, 1997; Nichols, Merkel, & Cordts, 1996; Spotts & Dwyer, 1996). As a result of not fully exploiting the representational characteristics of interactivity, the learning from various interactive software applications has not been consistently superior when compared to static representations (Spotts & Dwyer, 1996). Although overall success is not consistent, certain interactive applications are quite successful, including flight simulation programs to support pilot training, and games originally designed for entertainment have proven to be helpful in education (McFarlane, Sparrowhawke, & Heald, 2002).

One of the elements that make simulations and games so successful is the characteristic interaction and involvement of the learner in the activity/experience. In simulation environments and other successful interactive applications, the constraints of the interactive application map directly to the constraints of the task, making it easy for the user to learn by just using the environment. In flight simulation games for instance, the user learns to pilot an airplane by doing it: task, interaction and content are totally aligned. This learning also happens in microworlds or other higher level simulations, where the learner interacts with a system, testing their own preconceptions, learning through the interaction with the system. This concept is especially powerful if the learner is able to test and challenge his/her own models of the domain, thereby constructing new knowledge.

Multimedia has shown a positive effect in the development of higher cognitive skills in science learning (Frear, 1999; Iding, 2000b; Moore, 2000). Analysis of the value of static graphic representations have supported its value for complex scientific information visualization (Iding, 2000a, 2000b). The use of animated representations of abstract scientific concepts, has been related with an enhanced holistic understanding of the content (Blankenship & Dansereau, 2000; ChanLin, 1998; Nichols et al., 1996; Spotts & Dwyer, 1996). Some suggest that animation would enhance learning by allowing users to dynamically interact with the content, in a way that represents the dynamics of the process, thus improving their holistic understanding of the system (ChanLin, 1998; Mergendoller, 1997; Nichols et al., 1996), but there is no clear explanation of how this would be achieved, nor what learning processes could be supported by the interaction.

Many theoretical approaches have been used to design and analyze educational outcomes, with diverse focus on behavioral, social or cognitive issues involved in learning. The information processing theory (Bagui, 1998) and the theory of Dual Coding (A. Paivio, 1991; Allan Paivio, 1997) have strong support among instructional designers. These theories focus on the role of information stimulus and its relationship with sensory and cognitive input channels. Successful applications balance input load and processing capabilities. Newer approaches using computers to support generative activities have shown positive effects in the stimulation of metacognitive processes, also improving problem solving strategies (Azevedo, 2002; Clements & Nastasi, 1999; Hokanson & Hooper, 2000; Xiaodong, 2001). The use of interactive, inquiry-based learning environments has also successfully improved science learning for elementary, middle and high school students (Linn & Slotta, 2000).

Although these theories have contributed to the development and evaluation of interactive multimedia, current models fail to explain the observed inconsistencies in the effectivity of multimedia in education. Even though the relationship between content, tasks, and media has been extensively analyzed in cognitive science (Larkin & Simon, 1995; Scaife & Rogers, 1996; Zhang, 1997), the application of this knowledge in the design and evaluation of educative materials has been insufficient. Based on these observations, it would be reasonable to argue that the pedagogic power of a selected media would be related with its representational capabilities. The comprehension of this relationship and its magnitude will contribute not only to the design of new materials, and to the evaluation of existing applications, but also to increase the efficiency of our teaching strategies thus improving learning.

The following section is an overview of the evaluation of multimedia in health education in different contexts. This section provides information about the use of multimedia with focus on the learners, educational process supported by technology and the educational environments designed to foster learning.

Multimedia and Health Education

From an educational standpoint, multimedia applications must be designed to support and to enhance learning. The evaluation of learning outcomes of the introduction of multimedia in learning has been gradually taking a paramount place in educational research. Unfortunately, this type of evaluation confronts multiple methodological problems. In a recent review, Leterrie (Letterie, 2003) has shown that from a set of 210 reports of computer assisted instruction (CAI) in medicine, published between 1988 and 2000, only 11% correspond to comparative assessments of educational effectiveness (23 studies). From these, 12 compared CAI with traditional lectures. As we have previously mentioned, these results are similar to other reviews in the educational literature (Liao, 1998; Schitteck, Mattheos, Lyon, & Attstrom, 2001). On the other hand, reviews of the impact of specific technologies, such as simulations, have found evidence of the positive effects of specific product in medical education. According to Issenbert et al. (Issenberg, Gordon, Gordon, Safford, & Hart, 2001; Issenberg et al., 1999), simulations offer a potential solution for some of the current problems in skill training, especially some products designed as patient simulators, integrated throughout the medical curriculum, allowing deliberate practice and rehearsal of the desired skills. Furthermore, a review by Karim Qayumi (Karim Qayumi & Qayumi, 1999; Qayumi, 1997) stresses the importance

not only of curricular planning, but also of pedagogy and rich interactivity in order to virtually mimic the doctor-patient experience.

A good strategy to understand the evaluation of the educational impact of technology is to understand and differentiate some of the variables involved: What do I want to teach? Who am I going to teach it? How am I planning to do it? The first question is not only related with curricular decisions, but with a fundamental analysis related with the objectives of the educational process. There must be some relation between the kind of learning that we pursue and the strategies that we select to teach it. In general terms, we can distinguish two big categories of learning: declarative and procedural. These actually correspond to kinds of knowledge, but it is going to help us a first approach. Declarative knowledge is what we traditionally understand as knowledge and is what we most frequently evaluate. Declarative knowledge can be subdivided into three complexity layers: Structure, Dynamics and Cybernetics. The structural level deals with facts of a domain, raw data describing the characteristic elements of an object, problem or scenario. The second level will elaborate the relationships of these structures and how they change over time. The third level defines the control and causal relationships between the structures and dynamics of a system. In a medical scenario, a successful student of cardiovascular physiology, needs to know the structures of the cardiovascular system (vessels, heart chambers, valves, etc.). This student should also understand how these structures are related with each other and how they change over time. Finally, the student should be capable of explaining the levels of control of blood pressure or cardiac rhythm, etc.

Table 1.

Systems Complexity Levels

Level	Elements	Example
First	Structures	Anatomy
Second	Dynamics (temporal-spatial-causal relationships)	Respiration Dynamics. Structural relationships
Third	Control (Cybernetics)	Blood pressure regulation

Procedural knowledge refers to actions, or things that we do. These actions can be simple or complex, single or multiple. In order to be consistent with our previous description of declarative knowledge, we can also describe three levels of complexity: at the first level we have simple actions that do not require much coordination or previous knowledge, like tying knots or using the stethoscope, or puncturing a vein. The second level groups choreographies of actions that need not only perform an action, but also coordinate it with some declarative knowledge or actions, like auscultation, or performing a rectal exam. The third level of complexity involves some degree of understanding of the changes and behavior of a system. Usually this level implies some degree of decision making during the procedure, or adjustments to changes in the environment; CPR maneuvers or Laparoscopy procedures could be good examples of this level.

As you must have realized, these levels of complexity can coexist, and can also be used to decompose contents and tasks. At this point we are going to use this basic

classification to analyze educational research findings, and to relate them with the educational strategies chosen.

In terms of evaluation, declarative knowledge has been measured using diverse techniques and educational scenarios. Computer case-based learning and tutorials have proved to increase learning of declarative structural information (measured in diverse name recognition or alternative selection tasks) , and also to improve higher level skills that require understanding of dynamics and control of a system for interpretative and diagnostic tasks (Buzzell, Chamberlain, & Pintauro, 2002; Campagnolo, Stier, Sanchez, Foye, & DeLisa, 2003; Clark et al., 2000; Goldberg & McKhann, 2000; Maleck et al., 2001; Velan, Killen, Dziegielewski, & Kumar, 2002; Vichitvejpaisal et al., 2001). This kind of evaluation has not been restricted to learning for medical students, but also assessing learning in health consumers. The findings in this kind of research are consistent with the observations in the professional community, at least in regard of the capabilities of technology as support for declarative learning. It is also interesting to note that studies focusing on the evaluation of learning as means to improve self efficacy or decision making satisfaction among diverse groups of patients has also shown that technology based education can have positive impact (Murray et al., 2001a, 2001b; Shaw, Beebe, Tomshine, Adlis, & Cass, 2001; Valdez, Banerjee, Ackerson, & Fernandez, 2002; van Schaik, Ahmed, Suvakovic, & Hindmarsh, 1999; Yamada, Galecki, Goold, & Hogikyan, 1999).

Using multimedia to gain procedural knowledge has been extensively researched about the clinical use of simulations for training. Diverse procedures, like Laparoscopy or

Intravenous Catheter Training has been successfully developed using this kind of media (Engum, Jeffries, & Fisher, 2003). Simpler multimedia tutorials or interactive materials have had limited success, usually associated with gains in the declarative part of the procedure (the students know more *about* the procedure) (Hillenbrand & Larsen, 2002; J. C. Rosser et al., 2000; Stern et al., 2001; Treadwell, de Witt, & Grobler, 2002). Public health evaluation of the impact of multimedia evaluation in behavioral change supports the idea that we can use multimedia to improve our knowledge and also to support the development of new complex behaviors based on this learning. There is abundant evidence that multimedia interventions can improve the management of asthma, even improving clinical outcomes (Bartholomew et al., 2000; Homer et al., 2000; Krishna et al., 2003). These changes have also been observed in other behaviors, like diet, exercise, security or cancer prevention (Baranowski et al., 2003; Dragone, Bush, Jones, Bearison, & Kamani, 2002; Hornung et al., 2000; Lusk et al., 2003; Wiksten, Spanjer, & LaMaster, 2002).

One of the most interesting aspects of learning in health sciences is the process of gaining expertise. During the last decades important advances in our understanding of this process have been originated from the observation of changes in the characteristics of mental models during training or between learners with diverse levels of expertise (V. Patel, Evans, & Groen, 1989; V. L. Patel, Glaser, & Arocha, 2000).

Comparing and evaluating the changes in the characteristics of clinical reasoning suggest that the learning process involves changes in the way we cluster, process, and select information around a clinical problem. Evidence from think-aloud protocols supports the idea that higher levels of expertise are associated with higher

levels of organization (V. Patel et al., 1989; V. L. Patel et al., 2000). These findings are congruent with evidence of changes in the structure of mental models using innovative mathematical techniques as Pathfinder Networks Analysis, or Multidimensional Scaling (McGaghie, Boerger, McCrimmon, & Ravitch, 1994, 1996; McGaghie, McCrimmon, Mitchell, Thompson, & Ravitch, 2000).

From this research we could conclude that one important element in design should be to develop systems capable of supporting these organizational processes, metacognitive skills, and cognitive problem-solving heuristics. Even though technology seems to be capable of such role, it is still unclear what educational strategies and methods are capable of best fostering the development of these cognitive skills.

Even though it is usually recognized that learner characteristics are primordial to education, there hasn't been enough research to analyze which student variables need to be addressed in order to improve learning with technology. There is evidence that students enjoy multimedia education, especially when the programs are designed taking in consideration user friendliness or usability issues (Brearley Messer, Kan, Cameron, & Robinson, 2002; Chambers & Connor, 2002; Lemaire & Greene, 2002; Mattheos, Nattestad, Schitteck, & Attstrom, 2001; Takabayashi et al., 1999; Teichman & Richards, 1999; Volpe, Aquino, & Norato, 1998). Wilger published a review (Wilger & Catton, 2003) analyzing the impact of patient preference on learning. This study recognizes the differences among multimedia applications, highlighting the relevance of selection alternatives, and the need for further research in order to actually prove that this statement is true. It has also been recognized that learner's perception of learning is not necessarily related with objective testing results (Williams, Aubin, Harkin, & Cottrell,

2001). Finally, Lenert(Lenert, Ziegler, Lee, Unfred, & Mahmoud, 2000) published an article analyzing the effect of race and gender of characters in multimedia applications and its relationship with education. This study warns about the potential deleterious effect of a mismatch in these characteristics.

Health education is in a constant process of evolution, trying to accommodate for the increasing pressures to embed more content and to increase the relevance and efficiency of the educational process. There is also increasing awareness of the potentiality and relevance of information technology in order to improve clinical practice and education (Fleischer & Posel, 2003; Hamdorf & Hall, 2001; Mantas, 1998; Mantas & Diomidus, 1998; Zelmer & Stewart, 1998). This increased awareness is impacting decisions referent with the biomedical education curriculum. Concretely, this concern has been translated so far on an increase of the number of hours allocated to teach about technology and also in the discussion of new strategies to effectively use technology to foster learning. Institutionally, there is increasing discussion about the degree of preparedness to confront the challenges of technologically based education in the future (Macklin, 2000; Peroz, Bosel, & Lange, 2003; Wells et al., 2003).

Another byproduct of this curricular discussion is the increasing relevance of the educational models needed to implement technology in education. There has been interesting discussions about the role of computers in medical education (Bergeron, 1998; Daetwyler, 2003), stressing the importance of some strategies, like case-based or problem-based learning (E. Hovenga & Hay, 2000), as well as the relevance of adult and self-directed learning especially in distant learning models (Boyer, 1999; J. C. Rosser, Jr.,

Gabriel, Herman, & Murayama, 2001). As part of the same trends, collaboration is taking an important place in education, especially given the power of Internet and communications in this digital era (Headrick, Wilcock, & Batalden, 1998; E. J. Hovenga, 1999; Medelez Ortega, Burgun, Le Duff, & Le Beux, 2003). Current evaluations of the impact of changes in educational paradigms, have shown a slow shift towards student centered educational design (Alur, Fatima, & Joseph, 2002; Bockholt, West, & Bollenbacher, 2003; Eva, MacDonald, Rodenburg, & Regehr, 2000; Michea & Phelps, 2003).

Further research is required to evaluate the relationship of the educational model selected and educational outcomes, or the relationship of these models and the educational objectives and learner's characteristics. Educational research reflects a growing interest in multimedia technology, which has been materialized not only in increasing number of projects, but also in gradual improvements in research and evaluation (Cure, 2003; Premkumar, Hunter, Davison, & Jennett, 1998). During the last years, multimedia has begun to be regarded as evaluation tool in medical education (Guagnano, Merlitti, Manigrasso, Pace-Palitti, & Sensi, 2002); future evaluation must also address the role of this technology as standardized evaluation method.

New developments have shown an increasing awareness about the cognitive aspects associated with learning and especially about the interaction of these issues and technology. In the following section we are going to review some of the new perspectives born from discoveries in cognitive and information sciences, fundamental for the comprehension of paradigmatic shifts in multimedia design in education.

Distributed Representations and Educational Multimedia

Distributed representational theories have given us a detailed analysis of the relationship between content, its graphical representation, and the underlying cognitive processes (Scaife & Rogers, 1996). Choosing the appropriate representation, so that the constraints on the representation match the described content and learning task, will minimize the cognitive work for the user (inference) and improve learning (Barwise & Etchemendy, 1996). For this project, we will use a general analytic framework for external representations proposed by Zhang and Norman. This theory states that the form of a representation determines "...what information can be perceived, what [cognitive] processes can be activated, and what structures can be discovered from the specific representation." (Zhang, 1997).

In this theory, for a given cognitive task the components in the representational space are distributed between the internal and the external representational spaces. The internal representation resides in the person's mind, while the external representation resides in the external medium. For instance, in a game rules are memorized from a set of written instructions, while a set of game constraints can be embedded in or implied by physical configurations and can be perceived and followed by the user without being explicitly formulated. The distribution of these representations will affect the cognitive load for the task and the subject's cognitive behavior.

This framework was originated in the analysis of the impact of information representation in problem solving strategies (Zhang & Norman, 1994), and of the importance of information visualization to enhance access to information in graphic and tabular displays (relational information displays) (Zhang, 1997). Further research has extended the application of the theory to problem solving in dynamic complex environments (Chuah, Zhang, & Johnson, 2000; Zhang, Johnson, & Lu, 2001) and to analyze the use of static and animated diagrammatic representations (Cheng, Lowe, & Scaife, 2001; Jones & Scaife, 1999, 2000; Scaife & Rogers, 1996). External representations can serve as cognitive aids to improve understanding, by anchoring and structuring cognitive behavior, making information visible and sustainable, aiding processability by limiting abstraction, and through many other means (28).

A good representation must be able to explicitly preserve the required information (Barwise & Etchemendy, 1996), with a minimum of cognitive work for the subject, making learning easier. For instance, diagrams (Iding, 2000a) have been successfully used in identification, comparison and sequencing tasks. Series of images (multiples), organized in visual lists of objects or concepts can help viewers to analyze, compare, differentiate or decide (Tufte, 1997). Animations have been used to represent movement (Blankenship & Dansereau, 2000; Scaife & Rogers, 1996), and to illustrate complex structural and, functional and procedural relationships among objects and events, and it has proven to be a positive aid to teach procedural information (ChanLin, 1998).

We understand learning as the acquisition of new declarative and/or procedural knowledge. In technology supported learning, this process involves the interaction of the user and the interface. The Resources Model (Wright, Fields, & Harrison, 2000) is useful

to understand the process of interaction. In this recursive cycle, the individual recognizes changes in the environment, and adjusts their actions according their evaluation of the system. The perception and evaluation of the interaction is based on the user's goals. In order to successfully apply any media, it must at least be capable of representing this knowledge and the changes in a way that those changes can be easily interpreted in relation with user's goals. Finally, the interface must also be able to represent the history of interactions that have taken place in the search of the desired outcome (Hutchins, D., & A., 1986; Wright et al., 2000). For educational applications is especially critical to design interfaces sufficient to support the user goals and tasks, without hindering learning.

Theory-Based Taxonomy for Educational Contents

One of our main concerns about the theoretical basis for the use of technology in education has been related with the relationships between learning, the content and the selection of media for the task. We are developing a framework integrating learning theory to explain the process, systems' theory to give some structure to the contents and distributed representations theory to inform our selection of media. In the next section, we give an overview of the current state of this ongoing process.

The most widely used taxonomy of learning was described by Bloom and his colleagues (1956). This taxonomy allow us to categorize types of educational objectives for the cognitive domain, for things such as declarative knowledge (Reigeluth, 1999). The six hierarchical levels defined in this taxonomy have set a common language for

educators and instructional designers. The following table matches this taxonomy with the skill levels represented in the ACEP report.

Gagne's taxonomy offers a good cognitive layout to the ACEP scale. The Verbal Information stage of this taxonomy asks the learner to state or tell facts or events. The second level, Intellectual Skills, requires the subject to operate within the domain using symbols. Finally, the Cognitive Strategies level is focused in the subject's higher order capabilities to plan and coordinate actions within the domain.

Systems' theory, defines the main characteristics of dynamic system as the components, constraints and rules organizing sets of related elements (Johansen, 1994). This theoretical and methodological approach has helped science to describe and model sets of relationships in many complex systems such as biological systems, ecosystems, geological processes, and so forth. Many systems organize their behavior according to complex feedback loops that the learner must holistically understand to recognize and describe the patterns of the system, and to predict the future states of the system. In our framework, we use systems theory to categorize the types of educational content into three main sections: definition of **structures** (declarative knowledge), **dynamics** (changes and their parameters), and the **control rules** (feedback loops, complex interactive learning content). The third column in Table 1 represents the knowledge level from a systems perspective. This allows us to map the complexity of the knowledge to be represented in order to reach training objectives within each skill level.

Table 2.

Instructional taxonomies

Bloom	Gagne	System Analysis
Knowledge	Verbal Information	Structures
Comprehension		
Application	Intellectual Skill	Dynamics
Analysis	Cognitive Strategy	
Synthesis		
Evaluation		Control Rules

From research evidence we hypothesize that multimedia can be used to support learning of domain facts, with at least a verbal and intellectual skill level. Traditional presentations or tutorials seem to be successful vehicles for the static domain facts. Animations could be effective in giving a holistic overview of dynamic changes in a given system. Further research is needed to understand the role of interactivity and multimedia in higher levels of training, even though current evidence (especially for simulations) suggests an important role of immersive or highly interactive applications to facilitate higher level meaningful learning.

The determination of optimal representation forms for any given content is dependant on the nature of the content and the learning task at hand. The characteristics of the learner and his previous expertise in the domain will also influence the characteristics of the optimum educational solution. Multimedia applications offer a unique opportunity for the design of tailored interventions according with learners' needs

and preferences. Media fidelity and complexity need to be adequate to the capabilities of the target audience (Jenkinson, Woolrige, Wilson-Pawels, McCready, & Brierley, 2003). More research is required to define the nature of these relationships and to outline methods and strategies to operationalize them.

Research Needs

Even though over the past decade the quantity and quality of educational research has notoriously improved, there is still a demanding need for scientifically sound educational evaluation of the impact of technology. One of the main reasons behind the variability and inconsistency in educational technology evaluation resides in the high number of variables involved: Learners characteristics, especial requirements, educational environments, technology implementation, strategies and implementation, to mention some. Even though there are multiple steps to take in order to overcome these difficulties, we believe that developing processes and taxonomies capable of standardize our scientific observations is among the first ones. This research should also emphasize the role of media and especially the role of interaction as catalyst for the acquisition of higher order cognitive skills.

The evaluation of the cognitive issues associated with learning and multimedia should be the basis of a new generation of multimedia applications. These new applications should not only adopt information age paradigms such as learner centered education and tailored interventions, but also the undiscovered capabilities of highly interactive media and cognitive interventions.

One of the first steps towards this future is the development of research projects aware of the multiple variables involved as well as the generation of standards for the development and evaluation of educational materials. Current research show clear sign of improvement in the quality of the scientific evidence, but these improvements are not going to be enough unless these observations are joined by a wide theoretical basis in regards to learning, learner and technology.

References

- Adkins, S. S. (2002). *The 2002 U.S. market for e-learning and simulation* (Executive Summary): Brandon-hall.
- Alur, P., Fatima, K., & Joseph, R. (2002). Medical teaching websites: do they reflect the learning paradigm? *Medical Teacher*, 24(4), 422-424.
- Azevedo, R. (2002). Beyond Intelligent tutoring systems: Using computers as METAcognitive tools to enhance learning. *Instructional Science*(30), 31-45.
- Bagui, S. (1998). Reasons for increased learning using multimedia. *Journal of Education Multimedia and Hypermedia*, 7(1), 3-18.
- Baranowski, T., Baranowski, J., Cullen, K. W., Marsh, T., Islam, N., Zakeri, I., et al. (2003). Squire's Quest! Dietary outcome evaluation of a multimedia game. *Am J Prev Med*, 24(1), 52-61.
- Bartholomew, L. K., Gold, R. S., Parcel, G. S., Czyzewski, D. I., Sockrider, M. M., Fernandez, M., et al. (2000). Watch, Discover, Think, and Act: evaluation of computer-assisted instruction to improve asthma self-management in inner-city children. *Patient Educ Couns*, 39(2-3), 269-280.
- Barwise, J., & Etchemendy, J. (1996). Visual information and valid reasoning. In G. Allwein & J. Barwise (Eds.), *Logical reasoning with diagrams* (pp. 3-25). New York: Oxford University Press.
- Bergeron, B. P. (1998). Technology-enabled education. *Postgrad Med*, 103(5), 31-34.
- Blankenship, J., & Dansereau, D. (2000). The effect of animated node-link displays on information recall. *The Journal of Experimental Education*, 68(4), 293-308.

- Bockholt, S. M., West, J., & Bollenbacher, W. E. (2003). Cancer Cell Biology: A Student-Centered Instructional Module Exploring the Use of Multimedia to Enrich Interactive, Constructivist Learning of Science. *Cell Biol Educ*, 2, 35-50.
- Boyer, S. A. (1999). Courses without classrooms. *J Nurses Staff Dev*, 15(3), 116-119.
- Brearley Messer, L., Kan, K., Cameron, A., & Robinson, R. (2002). Teaching paediatric dentistry by multimedia: a three-year report. *Eur J Dent Educ*, 6(3), 128-138.
- Buzzell, P. R., Chamberlain, V. M., & Pintauro, S. J. (2002). The effectiveness of web-based, multimedia tutorials for teaching methods of human body composition analysis. *Adv Physiol Educ*, 26(1-4), 21-29.
- Campagnolo, D. I., Stier, K. T., Sanchez, W., Foye, P. M., & DeLisa, J. A. (2003). Spinal cord injury computer-assisted instruction for medical students. *Am J Phys Med Rehabil*, 82(4), 316-319.
- Chambers, M., & Connor, S. L. (2002). User-friendly technology to help family carers cope. *J Adv Nurs*, 40(5), 568-577.
- ChanLin, L.-j. (1998). Animation to teach students of different knowledge levels. *Journal of Instructional Psychology*, 25(3), 166-175.
- Cheng, P., Lowe, R., & Scaife, M. (2001). Cognitive science approaches to diagram use. *Artificial Intelligence Review*, 15(1/2), 79-94.
- Chuah, J., Zhang, J., & Johnson, T. R. (2000). *The representational effect in complex systems: a distributed representation approach*. Paper presented at the 22th Annual Conference of the Cognitive Science Society, Hillsdale, NJ.
- Clark, L. J., Watson, J., Cobbe, S. M., Reeve, W., Swann, I. J., & Macfarlane, P. W. (2000). CPR '98: a practical multimedia computer-based guide to

- cardiopulmonary resuscitation for medical students. *Resuscitation*, 44(2), 109-117.
- Clements, D., & Nastasi, B. (1999). Metacognition, learning, and educational computer environments. *Information Technology in Childhood Education*, 1999, 5-38.
- Cure, O. (2003). Evaluation methodology for a medical e-education patient-oriented information system. *Med Inform Internet Med*, 28(1), 1-5.
- Daetwyler, C. (2003). Computer supported education. *IMIA Yearbook of Medical Informatics 2003*, 1-4.
- Dragone, M. A., Bush, P. J., Jones, J. K., Bearison, D. J., & Kamani, S. (2002). Development and evaluation of an interactive CD-ROM for children with leukemia and their families. *Patient Educ Couns*, 46(4), 297-307.
- Engum, S. A., Jeffries, P., & Fisher, L. (2003). Intravenous catheter training system: computer-based education versus traditional learning methods. *Am J Surg*, 186(1), 67-74.
- Eva, K. W., MacDonald, R. D., Rodenburg, D., & Regehr, G. (2000). Maintaining the Characteristics of Effective Clinical Teachers in Computer Assisted Learning Environments. *Adv Health Sci Educ Theory Pract*, 5(3), 233-246.
- Fleiszer, D. M., & Posel, N. H. (2003). Development of an undergraduate medical curriculum: the McGill experience. *Acad Med*, 78(3), 265-269.
- Frear, V. (1999). Does interactive multimedia promote achievement and higher level thinking skills for today's science students? *British Journal of Educational Technology*, 30(4), 323-329.

- Goldberg, H. R., & McKhann, G. M. (2000). Student test scores are improved in a virtual learning environment. *Adv Physiol Educ*, 23(1), 59-66.
- Guagnano, M. T., Merlitti, D., Manigrasso, M. R., Pace-Palitti, V., & Sensi, S. (2002). New medical licensing examination using computer-based case simulations and standardized patients. *Acad Med*, 77(1), 87-90.
- Hamdorf, J. M., & Hall, J. C. (2001). The development of undergraduate curricula in surgery: I. General issues. *Aust N Z J Surg*, 71(1), 46-51.
- Headrick, L. A., Wilcock, P. M., & Batalden, P. B. (1998). Interprofessional working and continuing medical education. *Bmj*, 316(7133), 771-774.
- Hillenbrand, K. M., & Larsen, P. G. (2002). Effect of an educational intervention about breastfeeding on the knowledge, confidence, and behaviors of pediatric resident physicians. *Pediatrics*, 110(5), e59.
- Hokanson, B., & Hooper, S. (2000). Computers as cognitive media: examining the potential of computers in education. *Computers in Human Behavior*(16), 537-552.
- Homer, C., Susskind, O., Alpert, H. R., Owusu, M., Schneider, L., Rappaport, L. A., et al. (2000). An evaluation of an innovative multimedia educational software program for asthma management: report of a randomized, controlled trial. *Pediatrics*, 106(1 Pt 2), 210-215.
- Hornung, R. L., Lennon, P. A., Garrett, J. M., DeVellis, R. F., Weinberg, P. D., & Strecher, V. J. (2000). Interactive computer technology for skin cancer prevention targeting children. *Am J Prev Med*, 18(1), 69-76.
- Hovenga, E., & Hay, D. (2000). The role of informatics to support evidence-based practice and clinician education. *Aust Health Rev*, 23(3), 186-192.

- Hovenga, E. J. (1999). Using multi media to enhance a flexible learning program: lessons learned. *Proc AMIA Symp*, 530-534.
- Hutchins, E. L., D., H. J., & A., N. D. (1986). Direct Manipulation Interfaces. In N. D. A. & D. S. W. (Eds.), *User Centered System Design* (pp. 87-124). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Iding, M. (2000a). Can strategies facilitate learning from illustrated science texts? *International Journal of Instructional Media*, 27(3), 289-301.
- Iding, M. (2000b). Is seeing believing? Features of effective multimedia for learning science. *International Journal of Instructional Media*, 27(4), 403-415.
- Issenberg, S. B., Gordon, M. S., Gordon, D. L., Safford, R. E., & Hart, I. R. (2001). Simulation and new learning technologies. *Med Teach*, 23(1), 16-23.
- Issenberg, S. B., McGaghie, W. C., Hart, I. R., Mayer, J. W., Felner, J. M., Petrusa, E. R., et al. (1999). Simulation technology for health care professional skills training and assessment. *Jama*, 282(9), 861-866.
- Jenkinson, J., Woolrige, N., Wilson-Pawels, L., McCready, D., & Brierley, M. (2003). Development and Evaluation of the Sentinel Node Biopsy Continuing Professional Development Course. *Journal of Biocommunication*, 29(4).
- Johansen, O. (1994). El enfoque de los sistemas. In L. Noriega (Ed.), *Introducción a la Teoría General de Sistemas*. Balderas, Mexico: Limusa Noriega.
- Jones, S., & Scaife, M. (1999). *Diagram Representation: A Comparison of Animated and Static Formats*. Paper presented at the ED-MEDIA 99: World Conference on Educational Multimedia, Hypermedia and Telecommunications, Seattle.

- Jones, S., & Scaife, M. (2000). Animated Diagrams: An investigation into the cognitive effects of using animation to illustrate dynamic processes. *Lecture Notes in Artificial Intelligence, Theory & Applications of Diagrams*(1889), 231-244.
- Karim Qayumi, A., & Qayumi, T. (1999). Computer-assisted learning: cyberPatient--a step in the future of surgical education. *J Invest Surg*, 12(6), 307-317.
- Krishna, S., Francisco, B. D., Balas, E. A., Konig, P., Graff, G. R., & Madsen, R. W. (2003). Internet-enabled interactive multimedia asthma education program: a randomized trial. *Pediatrics*, 111(3), 503-510.
- Larkin, J., & Simon, H. (1995). Why a diagram is (sometimes) worth ten thousand words. In J. Glasgow, N. Hari Narayanan & B. Chandras Karan (Eds.), *Diagrammatic Reasoning*. Cambridge: MIT Press.
- Lemaire, E. D., & Greene, G. (2002). Continuing education in physical rehabilitation using Internet-based modules. *J Telemed Telecare*, 8(1), 19-24.
- Lenert, L. A., Ziegler, J., Lee, T., Unfred, C., & Mahmoud, R. (2000). The risks of multimedia methods: effects of actor's race and gender on preferences for health states. *J Am Med Inform Assoc*, 7(2), 177-185.
- Letterie, G. S. (2003). Medical education as a science: the quality of evidence for computer-assisted instruction. *Am J Obstet Gynecol*, 188(3), 849-853.
- Liao, Y.-k. (1998). Effects of hypermedia versus traditional instruction on students' achievement: a meta-analysis. *Journal of Research on Computing in Education*, 30(4), 341-359.
- Linn, M., & Slotta, J. (2000). WISE Science. *Educational Leadership*, 2000(October), 29-32.

- Lusk, S. L., Ronis, D. L., Kazanis, A. S., Eakin, B. L., Hong, O., & Raymond, D. M. (2003). Effectiveness of a tailored intervention to increase factory workers' use of hearing protection. *Nurs Res*, 52(5), 289-295.
- Macklin, D. (2000). Compact disc interactive: a multimedia solution for staff education. *J Nurses Staff Dev*, 16(3), 131-137.
- Maleck, M., Fischer, M. R., Kammer, B., Zeiler, C., Mangel, E., Schenk, F., et al. (2001). Do computers teach better? A media comparison study for case-based teaching in radiology. *Radiographics*, 21(4), 1025-1032.
- Mantas, J. (1998). NIGHTINGALE--a new perspective in nursing informatics education in Europe. *Stud Health Technol Inform*, 51, 102-113.
- Mantas, J., & Diomidus, M. (1998). Curriculum development and courseware implementation using World Wide Web technology. *Medinfo*, 9 Pt 2, 777-779.
- Mattheos, N., Nattestad, A., Schitteck, M., & Attstrom, R. (2001). A virtual classroom for undergraduate periodontology: a pilot study. *Eur J Dent Educ*, 5(4), 139-147.
- McFarlane, A., Sparrowhawke, A., & Heald, Y. (2002). *Report on the educational use of games*. Cambridge: TEEM.
- McGaghie, W. C., Boerger, R. L., McCrimmon, D. R., & Ravitch, M. M. (1994). Agreement among medical experts about the structure of concepts in pulmonary physiology. *Acad Med*, 69(10 Suppl), S78-80.
- McGaghie, W. C., Boerger, R. L., McCrimmon, D. R., & Ravitch, M. M. (1996). Learning pulmonary physiology: comparison of student and faculty knowledge structures. *Acad Med*, 71(1 Suppl), S13-15.

- McGaghie, W. C., McCrimmon, D. R., Mitchell, G., Thompson, J. A., & Ravitch, M. M. (2000). Quantitative concept mapping in pulmonary physiology: comparison of student and faculty knowledge structures. *Adv Physiol Educ*, 23(1), 72-81.
- Medelez Ortega, E., Burgun, A., Le Duff, F., & Le Beux, P. (2003). Collaborative environment for clinical reasoning and distance learning sessions. *Int J Med Inf*, 70(2-3), 345-351.
- Mergendoller, J. (1997). Sifting the hype: what research says about technology and learning. *Principal*, 76(Jan 1997), 12-14.
- Michael, J. (2001). The Claude Bernard Distinguished Lecture. In pursuit of meaningful learning. *Adv Physiol Educ*, 25(1-4), 145-158.
- Michea, Y., & Phelps, C. (2003, April 23-25, 2003). *Learning Management Systems: Functionality to Improve Learning?* Paper presented at the Teach Globally, Learn Locally: Innovations in Health and Biomedical Informatics Education in the 21st Century, Portland, Oregon.
- Moore, D. (2000). A framework for using multimedia within argumentation systems. *Journal of Education Multimedia and Hypermedia*, 9(2), 83-98.
- Murray, E., Davis, H., Tai, S. S., Coulter, A., Gray, A., & Haines, A. (2001a). Randomised controlled trial of an interactive multimedia decision aid on benign prostatic hypertrophy in primary care. *Bmj*, 323(7311), 493-496.
- Murray, E., Davis, H., Tai, S. S., Coulter, A., Gray, A., & Haines, A. (2001b). Randomised controlled trial of an interactive multimedia decision aid on hormone replacement therapy in primary care. *Bmj*, 323(7311), 490-493.

- Nichols, C., Merkel, S., & Cordts, M. (1996). The effect of computer animation on students understanding of microbiology. *Journal of Research on Computing in Education*, 28(Spring), 359-371.
- Olson, T. M., & Wisher, R. A. (2002). The Effectiveness of Web-Based Instruction: An Initial Inquiry. *International Review of Research in Open and Distance Learning*, 3(2).
- Paivio, A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology*(45), 255-287.
- Paivio, A. (1997). *Mental representations: A dual-coding approach*: Oxford Sciences Publications.
- Patel, V., Evans, D., & Groen, G. (1989). Biomedical Knowledge and Clinical Reasoning. In D. Evans & V. Patel (Eds.), *Cognitive Science in Medicine. Biomedical Modeling* (pp. 53-112). Cambridge, Massachusetts: The MIT Press.
- Patel, V. L., Glaser, R., & Arocha, J. F. (2000). Cognition and expertise: acquisition of medical competence. *Clin Invest Med*, 23(4), 256-260.
- Peroz, I., Bosel, C., & Lange, K. P. (2003). Representative survey of dental students about the present state of education, PC equipment and configuration requirements for a net-based dental education system. *Med Teach*, 25(4), 385-390.
- Premkumar, K., Hunter, W., Davison, J., & Jennett, P. (1998). Development and validation of an evaluation tool for multimedia resources in health education. *Int J Med Inf*, 50(1-3), 243-250.
- Qayumi, T. (1997). Computers and medical education. *J Invest Surg*, 10(6), vii-ix.

- Reigeluth, C. (1999). What is Instructional-Design Theory and How Is It Changing? In C. Reigeluth (Ed.), *Instructional-Design Theories and Models. A New Paradigm of Instructional Theory* (Vol. 2, pp. 5-29). Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers.
- Rosser, J. C., Herman, B., Risucci, D. A., Murayama, M., Rosser, L. E., & Merrell, R. C. (2000). Effectiveness of a CD-ROM multimedia tutorial in transferring cognitive knowledge essential for laparoscopic skill training. *Am J Surg*, 179(4), 320-324.
- Rosser, J. C., Jr., Gabriel, N., Herman, B., & Murayama, M. (2001). Telementoring and teleproctoring. *World J Surg*, 25(11), 1438-1448.
- Scaife, M., & Rogers, Y. (1996). External cognition: how do graphical representations work? *Int. J. Human-Computer Studies*, 45, 185-213.
- Schitteck, M., Mattheos, N., Lyon, H. C., & Attstrom, R. (2001). Computer assisted learning. A review. *Eur J Dent Educ*, 5(3), 93-100.
- Shaw, M. J., Beebe, T. J., Tomshine, P. A., Adlis, S. A., & Cass, O. W. (2001). A randomized, controlled trial of interactive, multimedia software for patient colonoscopy education. *J Clin Gastroenterol*, 32(2), 142-147.
- Spotts, J., & Dwyer, F. (1996). The effect of computer-generated animation on student achievement of different types of educational objectives. *International Journal of Instructional Media*, 23(4), 365-375.
- Stern, D. T., Mangrulkar, R. S., Gruppen, L. D., Lang, A. L., Grum, C. M., & Judge, R. D. (2001). Using a multimedia tool to improve cardiac auscultation knowledge and skills. *J Gen Intern Med*, 16(11), 763-769.

- Takabayashi, K., Tomita, M., Tsumoto, S., Suzuki, T., Yamazaki, S., Honda, M., et al. (1999). Computer-assisted instructions for patients with bronchial asthma. *Patient Educ Couns*, 38(3), 241-248.
- Teichman, J. M., & Richards, J. (1999). Multimedia to teach urology to medical students. *Urology*, 53(2), 267-270.
- Treadwell, I., de Witt, T. W., & Grobler, S. (2002). The impact of a new educational strategy on acquiring neonatology skills. *Med Educ*, 36(5), 441-448.
- Tufte, E. (1997). Multiples in space and time. In E. Tufte (Ed.), *Visual Explanations. Images and quantities, evidence and narrative* (pp. 104-119). Cheshire, Connecticut: Graphic Press.
- Valdez, A., Banerjee, K., Ackerson, L., & Fernandez, M. (2002). A multimedia breast cancer education intervention for low-income Latinas. *J Community Health*, 27(1), 33-51.
- van Schaik, P., Ahmed, T., Suvakovic, N., & Hindmarsh, J. R. (1999). Effect of an educational multimedia prostate program on the International Prostate Symptom Score. *Eur Urol*, 36(1), 36-39.
- Velan, G. M., Killen, M. T., Dziegielewski, M., & Kumar, R. K. (2002). Development and evaluation of a computer-assisted learning module on glomerulonephritis for medical students. *Med Teach*, 24(4), 412-416.
- Vichitvejpaisal, P., Sitthikongsak, S., Preechakoon, B., Kraiprasit, K., Parakkamodom, S., Manon, C., et al. (2001). Does computer-assisted instruction really help to improve the learning process? *Med Educ*, 35(10), 983-989.

- Volpe, R. M., Aquino, M. T., & Norato, D. Y. (1998). Multimedia system based on programmed instruction in medical genetics: construction and evaluation. *Int J Med Inf*, 50(1-3), 257-259.
- Wells, M. J., Wilkie, D. J., Brown, M. A., Corless, I. B., Farber, S. J., Judge, M. K., et al. (2003). Technology survey of nursing programs: implications for electronic end-of-life teaching tool development. *Comput Inform Nurs*, 21(1), 29-36.
- Wiksten, D. L., Spanjer, J., & LaMaster, K. (2002). Effective Use of Multimedia Technology in Athletic Training Education. *J Athl Train*, 37(4 Suppl), S213-S219.
- Wiljer, D., & Catton, P. (2003). Multimedia formats for patient education and health communication: does user preference matter? *J Med Internet Res*, 5(3), e19.
- Williams, C., Aubin, S., Harkin, P., & Cottrell, D. (2001). A randomized, controlled, single-blind trial of teaching provided by a computer-based multimedia package versus lecture. *Med Educ*, 35(9), 847-854.
- Wright, P., Fields, R., & Harrison, M. (2000). Analyzing human-computer interaction in distributed cognition: the resources model. *Human-Computer Interaction*, 15, 1-41.
- Xiaodong, L. (2001). Designing metacognitive activities. *Educational Technology Research and Development*, 49(2), 23-40.
- Yamada, R., Galecki, A. T., Goold, S. D., & Hogikyan, R. V. (1999). A multimedia intervention on cardiopulmonary resuscitation and advance directives. *J Gen Intern Med*, 14(9), 559-563.

Zelmer, A. C., & Stewart, S. M. (1998). Computers in the Faculty of Health Science--5 years on. *Int J Med Inf*, 50(1-3), 133-137.

Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science*, 21(2), 179-217.

Zhang, J., Johnson, T. R., & Lu, G. (2001). *The impact of representational formats on a dynamic decision making task*. Paper presented at the 3rd International Conference of Cognitive Science.

Zhang, J., & Norman, D. A. (1994). Representations in distributed cognitive tasks. *Cognitive Science*(18), 87-122.

Running head: MULTIDIMENSIONAL DESIGN OF EDUCATIONAL MULTIMEDIA

Multidimensional Design of Educational Multimedia

Yanko Michea MD

School of Health Information Sciences

The University of Texas Health Science Center at Houston

Abstract

Designing effective multimedia for education is an increasingly challenging task. Every day new technologies appear, and it is not self evident the better way to strategically use them to foster learning. This article presents a multidimensional framework for the design of educational multimedia. This framework integrates evidence from diverse disciplines such as: information and cognitive sciences, education, instructional design, information engineering, etc. The framework organizes the design tasks in three layers: Educational, Technological and Cognitive. It also describes strategies and methods to apply in each none of these layers. This framework should help designers to inform and document their media selection, and to foster the development of further research in this domain.

Multidimensional Design of Educational Multimedia

Education is changing, and technology has empowered this process. But do we know how to take advantage of these technological advances, producing consistent and reliable results? Since the boom of personal computing in the '80s, technology has been instrumental in the development of industrialized, mass media education. The explosive growth of the Internet and the improvements in personal computing has catalyzed these changes at increasing speeds. New cultural and market trends are pushing the development of consumer/learner oriented products, and personalization and tailoring are the new buzz words in the development jargon. There is also a special and increasing concern in the development of quality standards for technology-based educational materials or environments. Standardization should help us to produce high quality materials, and to develop a reliable production process.

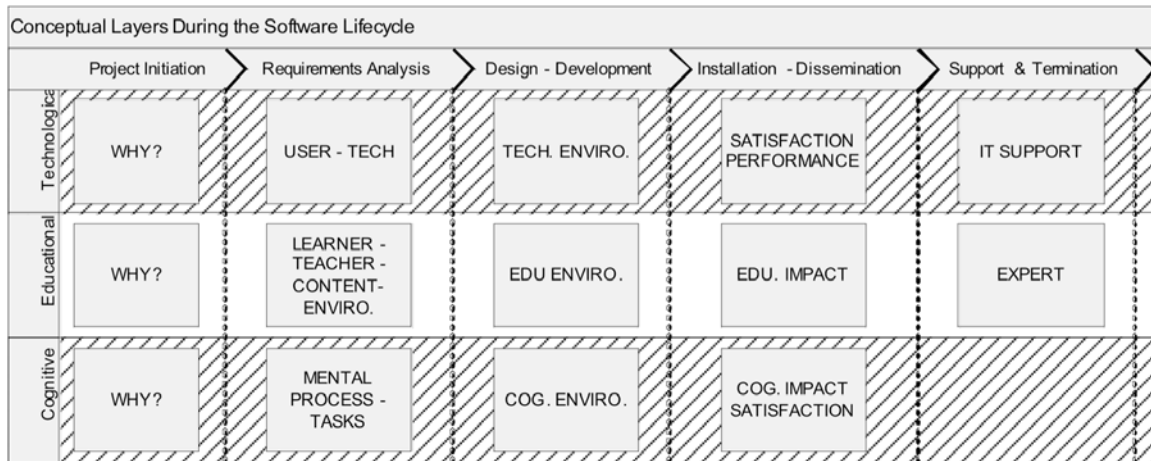
This article summarizes a framework to support the design and development of educational multimedia applications. Quality control in our educational environment has been focused on the assessment of multimedia software from an educational, technological, and human factors standpoint. We also have developed a process to help us to consistently succeed in our educational goals. Reliability that is especially important for research focused in increasing our understanding of the variables interacting in technology-based educational environments.

The framework that we propose has been influenced by diverse disciplines, such as: learning theory, instructional design, public health, information and cognitive sciences. Even though these disciplines have helped us to define a roadmap for our production process, the framework is not prescriptive. A good framework should help

you to organize and define the best strategy for any project, but the entrance point or the exact path of each project should be based on the available research evidence, and the special characteristics of each educational situation.

We understand this framework as a process map that should be described at multiple levels or layers. The first one is the Educational Layer; the main purpose of any educational software is to improve or support learning, and in order to fulfill this mission, it is mandatory to define and understand the characteristics of our learners, and their relationship with our content and learning objectives. The Technology layer is focused in design and elaboration of goals and objectives into a concrete set of technology-based strategies. The Cognitive layer is focused in the distinction of the best ways to trigger the cognitive processes that will better help the student to learn; interaction and information representation or visualization will further shape the way subjects' are going to interact with the information they need to learn.

The relevance of each layer is not constant during the process of developing educational multimedia, but it changes depending on the characteristics and evolution of the project. We are going to use this temporal dimension to reflect about the relevance of each dimension through time.

**Figure 2**

Software Life Cycle.

Software Life Cycle

Technology-based education design and development processes are associated or embedded within a set of steps traditionally described in software engineering as a “life cycle”. The lifecycle describes a roadmap to organize and standardize the production process. There are diverse flavors of this kind of map, that differ in the emphasis for a given step, the number of iterations within the model or the control or quality evaluation within the model. The lifecycle model that we present here summarizes the main aspects of almost any lifecycle description and is based in models previously reviewed by Scacchi (Scacchi, 2001) and Mayhew (Mayhew, 1999).

Project Initiation

The first step for any project is the generation of an idea and some level of justification or support for the relevance of the idea. In education this idea is usually associated to a new content that is going to be taught or to a need for improvement in some especially complex topic. Sometimes the idea is part of an exploratory effort, associated with the availability of a new technology that we believe that should improve learning. From a cognitive perspective, at this stage we are reflecting about the underlying mental processes and tasks associated with the topic to learn and the role of technology.

During this stage, we also build the network of expertise and resources that is going to support the development of the project. Educationally driven projects should develop a preliminary assessment of the needs and resources available at this point. We must be aware that most of the information and decisions are going to be general, and aimed towards the improvement of the project definition and scope. Any commitment with a specific technology should be avoided at this early stage, unless dictated by environmental or economical constraints.

Requirements Analysis:

This stage is dedicated to understanding and defining a target population of learners, and the objectives, scope, resources and needs for our project. Most of these definitions are concurrent, and linked together in a way that a change in one is going to affect the other. All these definitions are going to be evolving as long as we keep defining the project.

The educational layer of this stage will provide the learners' level of previous knowledge and any special needs. A definition of the content scope is going to be one of the first steps to define learning objectives and outcomes measures. The objectives are composed by three elements (Mager, 1997): Performance, Conditions, and Criterion. Performance describes the behavior that the student should show at the end of the activity. Usually, the behavior to be measured happens under some evaluation Conditions. These conditions are specific for a given performance; for example, be able to answer a question given a set of five alternatives, or be able to perform a procedure given a specific scenario. Finally, you need to define what will be accepted as a good or satisfactory behavior, a Criterion of performance.

The comparison of the current knowledge and the educational objectives should give us an overview of the existing gap. Depending on the scope of the project, all the contents will need to be placed in the context of the general curriculum. This stage will also need the assessment of the current learning environment and about any need derived of the changes that the project is going to introduce in the learning environment.

These steps are key for the definition of the scope of the project: increasing the specificity of our contents and preparing the way to the definition of the needs and requirements for our learners' population (Achtenhagen, 2001; Kuyper, De Hoog, & De Jong, 2001).

The technological layer defines the characteristics of the learners as computer users, the properties of the current educational environment, and its needs given the technological objectives. These objectives are derived from the selection of a technology to support our learning environment. In this stage we also define what are the general

design characteristics of our program (is it going to be stand-alone or coordinated with our LMS? What platform(s)? What media (Web, CD, DVD)? During this stage, usability and performance goals that are going to help us to know when the product is ready for installation or dissemination.

From a cognitive standpoint, at the end of this stage we should have modeled of the characteristics of the knowledge to be learned, the tasks involved in the learning process and the learner characteristics. We also need to start thinking about the strategies that should be implemented in order to facilitate learning. These strategies are the products of the available research evidence, theoretical commitments, the selected pedagogy, and the resources available.

Design and Development

Once we have defined our project's requirements, we can start working on the design and development of our multimedia application. This stage also requires the evaluation by experts and users in order to improve our product, and to refine our design. There are several differences in the way each model implements these steps: stepwise, cascading through the process or through multiple iterations with quick prototyping (see Figure 3). The process ends when we have reached our design goals as defined at the end of the requirements analysis.

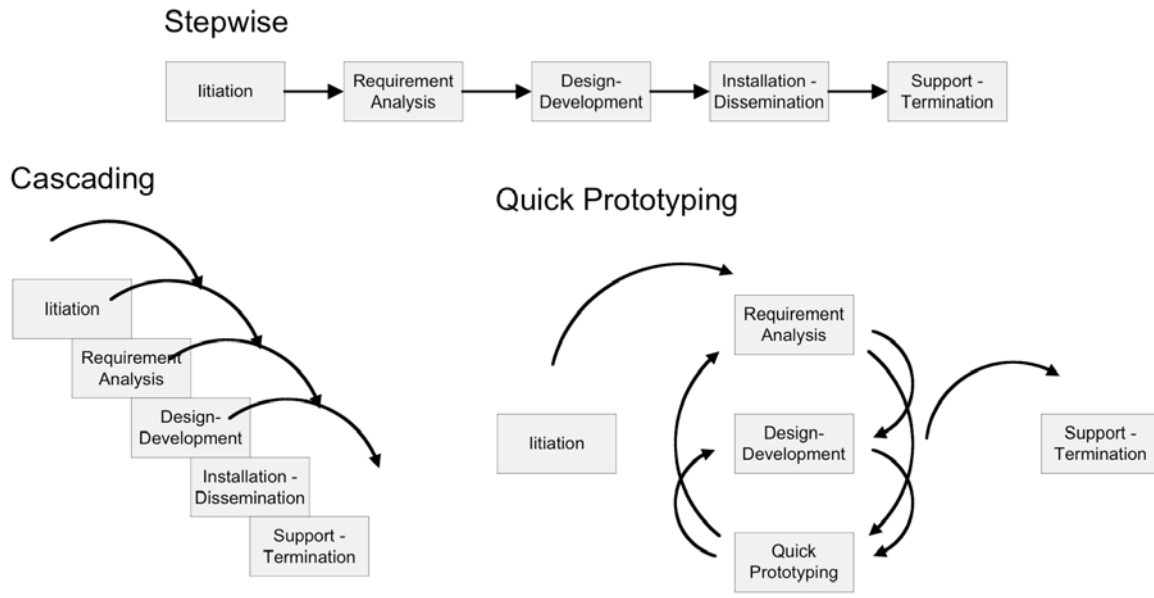


Figure 3
Software Life Cycle Implementation

In our experience, the transition from the general and theoretical preliminary discussions to a more software engineering process seems to be complex and variable. As part of our development process, we have developed a process that starts from the analysis of the information defined for each one of the layers (educational, technological and cognitive), not only organizing the information, but also helping us to define the development effort: the Development Matrix (DM).

Educational Layer

The Educational layer of the DM starts with the learning objectives that were defined in the previous section. Each objective will be associated with some content that has been defined as required in order to fully reach the objectives. Usually evaluation

items have been defined as part of the objectives development, but they should be included here if they are not part of them. Once we have defined the contents, we are ready to define the strategies and methods that we are going to use to teach these contents. In other words we are going to define the pedagogy to be used. The final product of this layer should be a documentation of the curriculum, including objectives, contents, evaluation, pedagogy, and activities (Units, modules) that are going to be part of our learning environment.

Table 3

The Development Matrix

	Objectives	Contents	Strategies	Products
Educational	Learning	Educational	Pedagogy	Units/Modules
	Objectives	Contents		
		Evaluation		
Technological	Tech. Platform	Applications	Functions	Software
	Usability and	Procedures	Navigation	Documentation
	Performance		Logic	and Prototyping
Cognitive	Process and	Interaction	Interaction	Human Centered
	Interaction	Environment	Maps	Recommendations

Technological Layer

The Technological layer of the DM starts with the definition of a technological platform, and our performance and usability objectives. The platform selection should

specify every detail about systems (Servers, Backend applications, OS, browser, plug-ins, etc) and media supported (DVD, CD, Internet, Mobile Computing, etc). The coordination with the educational layer will define the number of modules or applications to be developed given the contents and educational objectives. This coordination will also help us to define the functions, navigation and backend logic required to support the pedagogical methods and strategies as defined in the Educational Layer. At this time we should also implement the evaluation procedures (user surveys, usability evaluation, task analysis, etc) to determine the status of the objectives planned. The final product of this layer should be a working prototype of the application.

Cognitive Layer

The Cognitive layer is the most abstract of all, dedicated to evaluate the underlying processes related or triggered by the contents and by the media or tool used. In order to organize the information in this layer, we have adapted a methodology of human-centered distributed information design, described by Zhang et al.(Zhang, Patel, Johnson, Malin, & Smith, 2002). After a preliminary analysis of the main cognitive processes and tasks involved in learning (for instance, the processes and tasks in learning to dance are going to be extremely different from the tasks in learning anatomy, or history). From these models or cognitive maps, we can specify the way the contents should be represented and how the interaction should be designed. The objective of this layer is to optimize the content in a way that is going to decrease the cognitive work required, increasing the learning outcomes. This layer will also evaluate the task as between learner and technology, to evaluate and improve the way the subject interacts

with the software to not interfere with the achievement of the learning objectives. The final product of this layer is represented as a set of recommendations about the information flow, interaction with the contents (simulations, games, tutorials, etc.) and about software interface (knowledge manipulation, representation of the knowledge, interface design).

Table 4

User Centered Methodology – Analysis Levels

Level	Tasks	Products
User Analysis	Learner expertise and skills, previous knowledge, capacities and limitations	Prerequisites
Functional Analysis	Domain structure, dynamics and rules. Ideal distribution of domain between learner and environment.	Functional requirements. Information Flow
Task Analysis	Space and time distribution of activities and knowledge	
Representational Analysis	Define the best information display, flow and interaction	Information Displays, Interface and interaction design

The User Centered Methodology can be structured into four levels of analysis:

1. The first level is called User Analysis, and its goal is the definition of the learner as a user with a set of skills, knowledge and needs. All these characteristics are going to influence the way he or she interacts with the educational contents, methods and software interface that we are designing.
2. The second level is the Functional Analysis, where we assess the characteristics of the contents or tasks to learn. We define a domain structure, dynamics, and control systems in a hierarchical order of the concepts. As part of this level, we also define the distribution of this knowledge between students and system, and how this distribution should be at the end of the activity or training session.
3. A task analysis should be focused in the methods and strategies chosen (pedagogy) and its technological counterpart (the designed activities and navigation flow), checking for completeness and consistency and suggesting new activities to reinforce them.
4. Finally, a Representational Analysis should evaluate the way each one of the activities is going to represent the content, contrasting content level of complexity (structures, dynamics, and controls to be represented), dimensionality, and usability. This information is the basis of a set of suggestions for modifications in interface design and interaction that should decrease the cognitive load for each learning task.

The design and development of multimedia applications requires the integration of all these variables. The design process should be initiated at the Educational level, and then enriched by the Technological and Cognitive Layers. This is an iterative process that should help us to improve the educational value that the multimedia product. Defining the educational objectives and content scope of the project is fundamental for the design and development of educational multimedia. The final product of this stage is a working version of our software. This goal is achieved when we have reached the objectives defined for each one of the development layers.

Installation and Dissemination

The introduction of technology-based educational environments is a process that not only involves the development of the software itself, but also the introduction of changes in the traditional roles of students and educators within an organization. It should be part of the first stages of the requirements analysis that an assessment of the current workflow within the educational institution is completed. The endpoint of that analysis is the design of a plan to support the integration or migration to the new system.

Most projects require including training sessions for teachers and other support personnel to help them to learn to use and do basic troubleshooting of the developed software. The project developers should not assume that the product is going to be assimilated by the educators without any help. If the product was properly developed, teachers and students should have been involved since the beginning, and this should be a natural step within the process. If that was not the case, users should be included as soon

as possible, and the design stage should not be closed until user opinions and workflow analysis have been integrated in the design and development plans.

Bigger projects will require further attention to social and institutional dynamics in order to improve program adoption. Change management planning should include recognition and contact with organization stakeholders. Other aspects of installation and dissemination across the organization will depend on the characteristics of each institution.

Support and Termination

Once the educational environment is up and running, further efforts should be focused in the continuous development of support materials (FAQs, online help docs), patches or updates as long as the product is being used. These days, web-based learning environments can be easily kept updated given their centralized management. Other media like CD or DVD will have to plan a clear support policy and a clear mechanism to provide such updates to the user.

New Toolbox for Instructional Design

The implementation of this framework requires a complex set of tools consisting of traditional educational methodologies, like curriculum and educational objectives design, and methods or best practice recommendations from software engineering. Because of the increased awareness of the importance of human factors, usability and the

contribution of cognitive science, we have developed a process that integrates these new tools.

In the Educational Layer, there have been interesting efforts to increase the validity of the testing methods. New trends in standardization and adaptivity are fundamental for the development of computer assisted evaluations (Wainer et al., 2000). New evaluation tools, using simulations or virtual reality have been validated for specific domains. Cognitive science has contributed to our understanding of the mind and how it changes as we increase our expertise (V. Patel, Evans, & Groen, 1989; V. L. Patel, Glaser, & Arocha, 2000); so far these methodologies are hard to apply directly to education, but future research should provide us with new methodologies to assess mental model change. These innovations should impact the way we evaluate our educational outcomes, in terms of internal and external validity of our assessment.

The evaluation of the technological compliance with the development objectives is going to be commanded by the quality standards of each organization or project. Some institutions enforce the application of graphic or design standards, and sometimes technical standards, like standardize tags for web pages. There is also increased interest in the compliance with accessibility standards, to grant access to any user independently from physical limitations. The development team needs to specify the degree of compliance that is going to be considered satisfactory for the project at hand.

There are many methodologies to determine the degree of user satisfaction with the use of our software product. The simplest ones seems to be user surveys; most of the time these tools are designed by the development team, as general user satisfaction questionnaires or directed to some specific application feature. There are some

standardized surveys, like QUIS (Harper, Slaughter, & Norman, 1997), general enough to be used in diverse scenarios, but too long to be applied in a regular basis. Direct observation and interviews are another source of information about the use of the software, providing a holistic insight of the use of these products. Formal usability testing by experts should provide good information to evaluate the product compliance with industry standards, but are not that adequate to evaluate innovative products or non traditional multimedia applications.

There are many other evaluation tools, like task analysis, cognitive walkthrough techniques or think aloud protocols that will give us sophisticated information about other processes triggered by the interaction of our learners with the application. These tools are extremely valuable in experimental scenarios or in complex learning environments where cognitive characteristics of the task can be critical to successfully achieve the learning goals for the application. Unfortunately the application of these techniques is going to require extra expertise, time and funding.

Final Remarks

We have proposed a framework for the design and development of educative multimedia programs that encompasses diverse disciplines and organizes the process into three layers: Educational, Technological and Cognitive. The framework suggests a semi-structured process starting from learning objectives, from which technology is developed to support the educational strategies and methods envisioned for the learning

tasks and cognitive science knowledge is used to support and facilitate the required changes that mediate meaningful learning.

The overview of the tools required to finish this process shows a complex, iterative and multidisciplinary process where educators, developers and other experts interact to produce effective educational multimedia. Not all these tools and methods are going to be available for each project, but team leaders must be aware of their existence and about their appropriateness in each particular scenario.

There is not enough research yet to understand how each one of these variables impact educational outcomes. Developing frameworks and standards should help us to overcome this situation, helping us to develop evidence based recommendation for best practices in the development of educational multimedia.

References

- Achtenhagen, F. (2001). Criteria for the development of complex teaching-learning environments. *Instructional Science*, 29(4-5), 361-380.
- Harper, B., Slaughter, L., & Norman, K. (1997). *Questionnaire administration via the WWW: A validation and reliability study for a user satisfaction questionnaire*. Paper presented at the WebNet 97, Toronto, Canada.
- Kuyper, M., De Hoog, R., & De Jong, T. (2001). Modeling and supporting the authoring process of multimedia simulation based educational software: A knowledge engineering approach. *Instructional Science*, 29(4-5), 337-359.

- Mager, R. F. (1997). *Preparing Instructional Objectives. A critical tool in the development of effective instruction* (Third ed.). Atlanta: The Center for Effective Performance, Inc.
- Mayhew, D. J. (1999). Introduction. In *The Usability Engineering Lifecycle: a Practitioner's Handbook for User Interface Design* (pp. 1-31). San Francisco, California: Morgan Kaufmann Publishers, Inc.
- Patel, V., Evans, D., & Groen, G. (1989). Biomedical Knowledge and Clinical Reasoning. In D. Evans & V. Patel (Eds.), *Cognitive Science in Medicine. Biomedical Modeling* (pp. 53-112). Cambridge, Massachusetts: The MIT Press.
- Patel, V. L., Glaser, R., & Arocha, J. F. (2000). Cognition and expertise: acquisition of medical competence. *Clin Invest Med*, 23(4), 256-260.
- Scacchi, W. (2001). Process Models in Software Engineering. In J. J. Marciniak (Ed.), *Encyclopedia of Software Engineering* (2nd ed., pp. 993-1005). New York: John Wiley & Sons, Inc.
- Wainer, H., Dorans, N. J., Flaugher, R., Green, B. F., Mislevy, R. J., Steinberg, L., et al. (2000). *Computerized Adaptive Testing: A Primer* (2nd ed.): Lawrence Erlbaum Associates.
- Zhang, J., Patel, V. L., Johnson, K. A., Malin, J., & Smith, J. W. (2002). Designing human-centered distributed information systems. *IEEE Intelligent Systems*, 17(5), 42-47.

Running Title: CORRELATIONS IN CONCEPTUAL MODEL REPRESENTATIONS

Correlations in Conceptual Model Representations: Think Aloud vs. Pathfinder Network

Yanko F. Michea MD

School of Health Information Sciences

The University of Texas Health Science Center at Houston

Abstract

The within-subject conceptual correlation of mental models produced using a verbal protocol (Think-Aloud Protocol [TAP]) and from proximity data (Pathfinder Network) was investigated. The data was obtained in a single intervention recording first the verbal protocol and second the proximity data using a Likert scale questionnaire. The concepts and links for the verbal protocol were then homologated to concepts and links in the Pathfinder Network (PFN). The analysis of the conceptual links common to both models shows a linear correlation between the total number of links present in the TAP network and the number of common links in the PFN. The results indicated a significantly higher number of conceptual links in the Pathfinder Network. Further analysis of this relationship suggests that PFN could be a low-sensitivity but high-specificity indicator for conceptual links. These findings support the hypothesis of the existence of a correlation of conceptual models obtained these very different techniques.

Correlations in Conceptual Model Representations: Think Aloud vs. Pathfinder Network

How can we assess meaningful learning? There is increasing awareness in health education of the importance of assessing learning not just in terms of verbatim repetition of facts, but also in terms of the development of increasingly complex cognitive skills that will enable the learner to successfully solve clinical problems and to gain new skills as a life-long independent learner. Meaningful Learning is the term commonly used to describe this cognitively complex type of learning (J. Michael, 2001). In order to fulfill these educational goals we must keep working on the development of new assessment methodologies to help us to understand the characteristics of the learning process and the educational outcomes that could be measured to evaluate this process. From a cognitive perspective, these strategies should be designed to foster changes that will sustain this meaningful learning and that will be reflected in changes in the learner's mental models (V. L. Patel, Glaser, & Arocha, 2000).

The objective of this project was to contribute to the development of this methodological framework comparing two different approaches to the evaluation of mental models: Think Aloud Protocol (TAP) and Pathfinder Network (PFN). TAP is the gold standard for the qualitative assessment of mental models, and it has been widely used in medicine to assess and model the development of expertise in health professionals. This method requires the subject to speak everything that comes to his mind as a task is being completed. This verbal protocol is recorded, transcribed and analyzed using a theoretical framework defined by the researcher (Ericsson & Simon,

1984). Studies using this method have the ability to differentiate experts from novices in terms of reasoning patterns, knowledge organization, types of errors, rules, and data interpretation (Coderre, Mandin, Harasym, & Fick, 2003; Kushniruk & Patel, 1998; Kushniruk, Patel, & Marley, 1998; V. Patel, Evans, & Groen, 1989; V. L. Patel, Arocha, Diermeier, How, & Mottur-Pilson, 2001; V. L. Patel et al., 2000). TAP has also been a valuable method to model cognition in other domains and tasks, helping engineers and software developers to understand decision making and task performance (Lamond, Crow, Chase, Doggen, & Swinkels, 1996; Niessen, Eyferth, & Bierwagen, 1999). From an educational standpoint, one of the problems with this methodology is that even though the information provided can be a useful guide in the design and evaluation of learning environments, its applicability in larger scales can be too expensive, and impractical.

PFN is a method based on the analysis of conceptual proximity data provided by an individual (Schvaneveldt, 1990). The data is gathered by presenting a subject with a series of concept couples or terms that he or she must evaluate in terms of relatedness or proximity by representing it on a likert scale. The method involves multiple techniques that allow the researchers to derive a two-dimensional network model of the concepts. The PFN analysis also provides us with information about the coherence of the model, the weight or distance between the concepts in this representation. Coherence is measured based on the assumption of transitivity of the relations: if the subject relates two concepts, like $A \rightarrow B$ and then also relates $B \rightarrow C$, then A should be also related with C . The analysis provided by this method is similar to multidimensional scaling techniques, with the only advantage of generating a two dimensional representation of the relations.

PFN has been successfully applied in the assessment of conceptual structures (Fabricius, Nagoshi, & MacKinnon, 1997). In health sciences, researchers have used PFN to analyze conceptual networks for respiratory physiology, comparing performance of experts and non-experts (McGaghie, Boerger, McCrimmon, & Ravitch, 1994, 1996; McGaghie, McCrimmon, Mitchell, Thompson, & Ravitch, 2000). The results of this research support the use of this kind of models as a feasible way to assess conceptual relatedness. Coherence and model similarity have been successfully used to differentiate expertise levels in different domains (Schvaneveldt, 1990), but the results with physiology models are not as conclusive (McGaghie et al., 2000). However, little attention has been given to the relationship between these models and the conceptual models obtained with other qualitative techniques, especially with the application of verbal protocols such as TAP.

This research project has been designed to explore these relationships, specifically in terms of the correlation of the concepts elicited with the TAP and the ones derived with PFN. In other words, we expect that the occurrence of a concept in a model derived from the TAP should be able to predict the appearance of an equivalent concept in a model generated with a PFN. We also believe that the non-appearance of a concept in a TAP model should also be able to predict its non appearance in the PFN model. We have selected a respiratory physiology topic based on previous research evaluating respiratory physiology models, and the specific problem of respiratory response to exercise based in previous evidence of a high prevalence of conceptual problems among health students and professionals (J. Michael, 2002; J. A. Michael, 1998; J. A. Michael et al., 1999).

Method

This study compares within-subject representation of mental models using two alternative methods: TAP and PFN. The mental models will represent the conceptual map of understanding of the physiologic response of the respiratory system to exercise. Each subject will first respond to the TAP and after that to the PFN. This sequence was selected to avoid interference that potentially could come from the presentation of the list of concepts before the verbal protocol. If we had presented the PFN assessment first, we would have exposed our subjects to a set of “expert” concepts which eventually would have increased their occurrence in the TAP more as an artifact than as a natural subject’s response.

Participants

Volunteer research subjects were recruited with the only requirement of having previous knowledge of physiology (at least one previous course of human physiology was required). All the experiment took place in front of a computer, and all data was directly collected to a database. Verbal protocol section of the experiment was also videotaped. Sequence of events for each subject:

1. Warm-up exercise: three short talk-aloud example exercises
(Ericsson & Simon, 1984).
2. Demographics form completed by the subject.
3. Talk Aloud Protocol began when the Respiratory Physiology and Exercise scenario was presented. Researcher was present all the time, cueing the

subject to continue speaking out loud if the subject stopped talking; all the interaction was recorded and videotaped.

4. PFN: Once the TAP was finished, the subject had to answer a 52 item questionnaire. Each item was composed of two concepts and the subject was required to grade them according to degree of functional relatedness. The concepts were randomized within each item; the items order was also randomized.

Talk Aloud Protocol

The recorded protocol was transcribed and analyzed according to a system's analysis framework (Johansen, 1994). This framework conceptualizes the components of a system in three categories:

1. Structural Components: Structures, concepts, constants, and other objects of the system.
2. Dynamics: Temporal, spatial or functional relationships between Structural Components
3. Control: Coordination of at least two dynamic relationships in order to reach a more desirable state of the system.

Two researchers analyzed the elements in each category were then classified as pertaining to the system or external to the system, and a diagram or model representing these elements was then prepared. The count of each category was stored for further analysis. Inter-rater reliability was assessed for the protocol analysis (kappa).

Pathfinder Network

Two domain experts developed a list of 14 concepts considered relevant building blocks to model the respiratory response to exercise. The relationship between concepts was considered symmetric, which produced a total of 91 relationships. As preliminary testing showed that subjects loss attention after 50 items, we decided to constraint the list to the most meaningful relationships for the task. The eliminated couples corresponded with relationships that were considered redundant or confounding (like ventral and dorsal respiratory groups, inspiratory muscles and ancillary inspiratory muscles) or relationships that will not further clarify the characteristics of the conceptual framework. After all these review, a list of 52 relationships was built. The research subjects were asked to rank the degree of functional relatedness for each one of these couples, on a scale ranging from 1 (not related at all) to 10 (highly related) .A web based application was developed to randomly present the questionnaire items and to store the subjects' answers. Questionnaire internal reliability was assessed using Cronbach's alpha reliability estimate.

Data Analysis

PFN were determined using KNOT ("KNOT," 2004), a software build around the pathfinder network generation algorithm that generates the networks, and all the proximity data, coherence, and similarity statistics needed for the analysis. Each network is composed by nodes (concepts), links between these concepts and weight or distance between the linked nodes.

In order to compare the concepts present in both networks for each subject, two researchers matched the concepts present in the TA network with its semantic equivalent

in the PNF. This matching process was performed just in order to standardize the use of terms, avoiding any change in the actual structure of the relationships. Inter-rater reliability was tested using kappa analysis. Finally, the data was analyzed to evaluate significant correlations between concepts in both models (TAP and PNF) and predictive value of the models.

Results

Research Subjects

A sample of 17 volunteers was recruited at our institution. The sample comprised 10 male and 7 female, with an age range of 26 - 62 ($M=37.2$, $SD=10.33$). The majority of the subjects were MDs (11 subjects), 4 subjects hold a Masters or PhD degree, and 2 subjects were Bachelors.

Think Aloud Protocol

The transcribed data was analyzed by one researcher in order to detect the different structures of the system, the dynamics or relationships and the control loops in each map. With this method, the range of system Structures detected was between 5 and 21 ($M=11.1$, $SD=4.59$). The Dynamics elements were between 6 and 21 ($M=12.53$, $SD=5.51$), and the number of Control loops identified in range from 0 to 3 ($M=1.4$, $SD=0.93$). In order to assess reliability of the observations, the data collected by this researcher were then correlated with the assessment of a second subject specifically trained for this task ($Pearson\ r = 0.958$; $P=0.01$). Table 1 summarizes the total number of

elements presented by the subjects. Figure 1 represents two actual models derived from the verbal protocol. There was no significant difference in the number of structures, dynamics or control elements identified depending on gender, age or education.

Table 5

TAP total findings.

	Congruent	Incongruent	Total
Structures	174 (92)	15(8)	189
Dynamics	152 (71)	61(29)	213
Control	16(70)	7(30)	23

Note: Numbers in parenthesis represent percentages per category. *Congruent* elements are the ones within the system under analysis; *Incongruent* elements were elements outside the scope of the system or non existent structures.

Each network was analyzed and coded according to the conceptual links previously defined for the PFN. Using this method, 39 different kinds of links were identified throughout the 17 maps. Table 6 presents the most frequent relationships or links found and the number of occurrences or frequency in our population.

Table 6

Ten most frequently linked concepts in TAP.

Link	Frequency
PaO ₂ and Respiratory Rate	8

Ventral Respiratory Group (Respiratory Control Center) and	
Inspiratory Muscles	7
PaCO ₂ and Respiratory Rate	7
Dorsal Respiratory Group (Respiratory Control Center) and	
Inspiratory Muscles	5
Dorsal Respiratory Group (Respiratory Control Center) and Ancillary	
Expiratory Muscles	4
Ventral Respiratory Group (Respiratory Control Center) and Ancillary	
Expiratory Muscles	4
Central Sensors and PaO ₂	4
Central Sensors and Respiratory Rate	4
Central Nervous System and Respiratory Rate	4
PaO ₂ and Respiratory Volume	4

Pathfinder Network

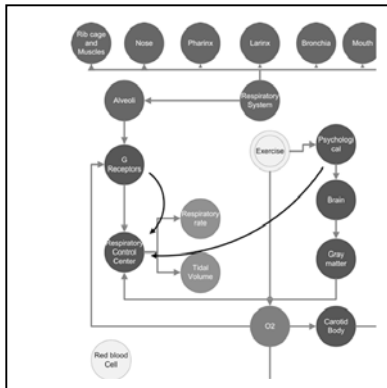
The reliability index for the items list was found satisfactory (*Cronbach's Alpha* = 0.713). All data was successfully collected in a SQL database and from there prepared for analysis with a network analysis program: KNOT. A level of coherence for the models over 0.2 is considered acceptable for the models; this level was achieved in all but one of the subjects (M=0.49, SD=0.18). Even though all the networks shared the same 14 nodes, the distribution of the links is unique to each one; there are a total of 330 links across the sample, which are present in numbers ranging from 14 to 25 per map (M=19.41, SD=4.8).

The count of occurrences per link type across the sample varies between 2 to 13 times (M=6.34, SD=2.78). Table 7 presents the most frequent links in our PFN maps.

Table 7

Most frequently linked concepts in PNF

Link	Frequency
PaCO ₂ and Respiratory Rate	13
pH and Respiratory Rate	12
Central Nervous System and Inspiratory Muscles	11
Central Nervous System and Ancillary Expiratory Muscles	
Dorsal Respiratory Group (Respiratory Control Center) and Ancillary Expiratory Muscles	11
Central Nervous System and Ancillary Expiratory Muscles	11
Dorsal Respiratory Group (Respiratory Control Center) and Expiratory Muscles	10
Ventral Respiratory Group (Respiratory Control Center) and Inspiratory Muscles	10
pH and Peripheral Sensors	10
Central Sensors and PaCO ₂	9
Central Sensors and PaO ₂	9
Central Nervous System and Expiratory Muscles	9

**Figure 4**

Examples of Conceptual Model maps using TAP (left), and PFN (right)

Comparing Models

Subject 1

There was a significant difference in the number of links per model: A total of 167 links were recognized in the TAP derived models while a total of 328 links were detected using PFN ($p < 0.001$).

A correlation analysis associating the total number of links present in the TAP model and the ones appearing in the PFN model was not significant ($r^2 = 0.1760$, $p = 0.09$).

As PFN models were used as the control for this exercise, they had a larger number of conceptual links than the TAP ones. The links that were absent in the PFN should be knowledge that must be also absent in the TAP models. As a way to test this assumption, we filtered out these “absent” PFN links, and correlated these subset with the total number of TAP links. The analysis performed comparing the total number of TAP model links related with the PFN-filtered links showed a much higher correlation ($r^2 = 0.7947$, $p < 0.0001$). The linear regression model for this data set is represented in Figure 5.

Subject 2

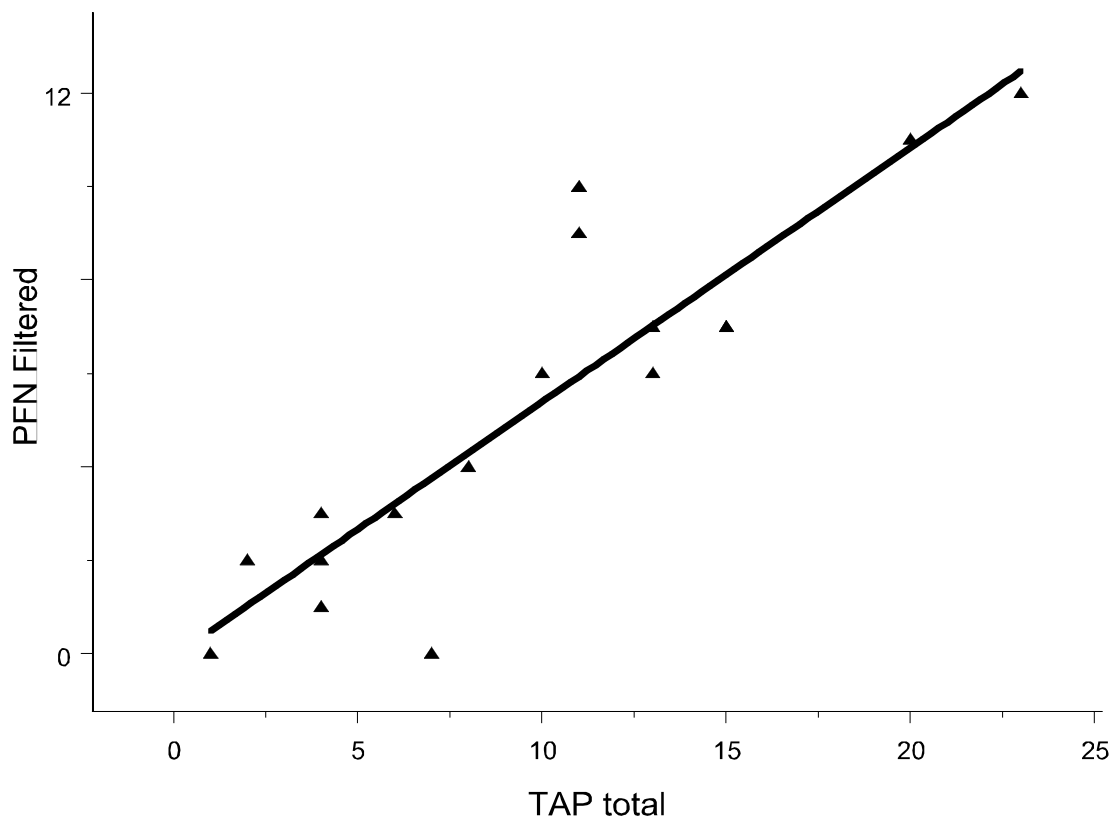


Figure 5

Linear regression model

The next step was to analyze the relationship between TAP results and PFN models using the latest one as a predictor or diagnostic test for the links in the TAP model (our gold standard). In order to do that we compare the links present in both models over the total number of possible links, looking for link agreement between models; the results of this evaluation are show in Table 8.

Table 8

Link agreement predictive model data

	PFN Present	PFN Absent	Total
TAP Present	90 (10%)	77 (9%)	167 (19%)
TAP Absent	238 (27%)	479(54%)	717 (81%)
Total	328 (37%)	556(63%)	884

The row/column association for this table was extremely significant (Fisher's Exact Test, two sided $p<0.0001$). Further analysis of shown high specificity of PFN but a low sensitivity for our sample (see Table 9).

Table 9

Sensitivity and specificity analysis.

Variable	Value	95% Confidence Interval
Sensitivity	0.2744	0.2266 to 0.3254
Specificity	0.8615	0.8296 to 0.8890
Positive Predictive Value	0.5389	0.4598 to 0.6157
Negative Predictive Value	0.6681	0.6318 to 0.7020
Likelihood Ratio	1.981	

Discussion

The objective of this study was to compare the within-subject representation of mental models using two alternative methods: TAP and PFN. We were interested specifically in understanding the correlations existing between the models obtained with these two different methodologies. The method used to achieve this objective required several steps towards the standardization of the terms used to describe the concepts for this domain. In one hand, the research subjects generate from their verbal protocols (TAP) terms usually more general or unspecific compared with the ones defined by our panel of experts for the quantitative model (PFN). The analysis and comparison of the networks was achieved with careful attention to the consistency and reliability of this standardization process.

Comparing the content of both models in terms of number of nodes and links present, it is immediately evident that the information contained is different. Given the characteristics of our sample (most of them have had physiology training more than 5 years ago), the descriptions of the respiratory system were usually general and unspecific. The number of links in these TAP derived models was significantly different from the number of links present in PFN models. It is most likely that the subjects were not capable of remembering the terms during the TAP, but that they were capable of recognizing the concepts once presented in the PFN questionnaire. The PFN questionnaire also required the subjects to select an alternative for each one of the questions, somehow pushing the subjects to guess if they didn't recognize one term. The network coherence data supports the argument that even though there should have been

some degree of guessing in these answers, it was not enough to affect the structure of the network, or at least that the guessed answers were consistent throughout the questionnaire.

We were especially interested in the coherence of both models. There was a clear correlation between the numbers of linked terms appearing in the TAP model with the number of correspondent links in the PFN model. A model of linear regression was successfully applied to this relationship. The results were not reproducible if we compare TAP and PFN total link counts. It is our impression that this is due to the higher number of links represented solely in the PFN model. These unique nodes must appear as a byproduct of the recall of new concepts that were not spontaneously present in the TAP. As we investigated the predictive value, specificity and sensitivity of the PNF model we found more evidence that there is a strong correlation between the positive findings in PFN and TAP models, and evidence suggesting that the model can be highly specific for this relationship.

The results of this research support the hypothesis of a close relationship between mental models obtained using both methods, and also open new questions about the nature of this relationship. In our research, there were several intermediate steps that were taken before we could compare the maps. In this research we assumed that the language that subjects and experts were going to use to define the structures of the system was going to be much similar than it actually was. Future research should design the conceptual lists for PFN should consider and incorporate these classification issues beforehand in order to simplify evaluation and validation of the measures. In complex systems, the number of concepts and the subsequent number of relationships to be tested

could hinder the reliability of the results given the fatigue of the research subjects. More research is needed in order to develop consistent methodologies to select and streamline the term lists in order to increase the reliability of the list of relationships used. We strongly believe that quantitative methods like PFN can be excellent tools in the assessment of mental models, and further research is needed in order to define their relationship with specific tasks like problem solving or learning.

References

- Coderre, S., Mandin, H., Harasym, P. H., & Fick, G. H. (2003). Diagnostic reasoning strategies and diagnostic success. *Med Educ*, 37(8), 695-703.
- Ericsson, K. A., & Simon, H. A. (1984). *Protocol Analysis. Verbal Reports as Data*. Cambridge: MIT Press.
- Fabricsius, W. V., Nagoshi, C. T., & MacKinnon, D. P. (1997). Concepts of drugs: differences in conceptual structure across groups with different levels of drug experience. *Addiction*, 92(7), 847-858.
- Johansen, O. (1994). El enfoque de los sistemas. In L. Noriega (Ed.), *Introducción a la Teoría General de Sistemas*. Balderas, Mexico: Limusa Noriega.
- KNOT. (2004). Gilbert, AZ: Interlink Inc.
- Kushniruk, A. W., & Patel, V. L. (1998). Cognitive evaluation of decision making processes and assessment of information technology in medicine. *Int J Med Inf*, 51(2-3), 83-90.
- Kushniruk, A. W., Patel, V. L., & Marley, A. A. (1998). Small worlds and medical expertise: implications for medical cognition and knowledge engineering. *Int J Med Inf*, 49(3), 255-271.
- Lamond, D., Crow, R., Chase, J., Doggen, K., & Swinkels, M. (1996). Information sources used in decision making: considerations for simulation development. *Int J Nurs Stud*, 33(1), 47-57.
- McGaghie, W. C., Boerger, R. L., McCrimmon, D. R., & Ravitch, M. M. (1994). Agreement among medical experts about the structure of concepts in pulmonary physiology. *Acad Med*, 69(10 Suppl), S78-80.
- McGaghie, W. C., Boerger, R. L., McCrimmon, D. R., & Ravitch, M. M. (1996). Learning pulmonary physiology: comparison of student and faculty knowledge structures. *Acad Med*, 71(1 Suppl), S13-15.
- McGaghie, W. C., McCrimmon, D. R., Mitchell, G., Thompson, J. A., & Ravitch, M. M. (2000). Quantitative concept mapping in pulmonary physiology: comparison of student and faculty knowledge structures. *Adv Physiol Educ*, 23(1), 72-81.
- Michael, J. (2001). The Claude Bernard Distinguished Lecture. In pursuit of meaningful learning. *Adv Physiol Educ*, 25(1-4), 145-158.

- Michael, J. (2002). Misconceptions-what students think they know. *Adv Physiol Educ*, 26(1), 5-6.
- Michael, J. A. (1998). Students' misconceptions about perceived physiological responses. *Am J Physiol*, 274(Adv. Physiol. Educ. 19), S90-98.
- Michael, J. A., Richardson, D., Rovick, A., Modell, H., Bruce, D., Horwitz, B., et al. (1999). Undergraduate students' misconceptions about respiratory physiology. *Am J Physiol*, 277(Adv. Physiol. Educ. 22), S127-135.
- Niessen, C., Eyferth, K., & Bierwagen, T. (1999). Modelling cognitive processes of experienced air traffic controllers. *Ergonomics*, 42(11), 1507-1520.
- Patel, V., Evans, D., & Groen, G. (1989). Biomedical Knowledge and Clinical Reasoning. In D. Evans & V. Patel (Eds.), *Cognitive Science in Medicine. Biomedical Modeling* (pp. 53-112). Cambridge, Massachusetts: The MIT Press.
- Patel, V. L., Arocha, J. F., Diermeier, M., How, J., & Mottur-Pilson, C. (2001). Cognitive psychological studies of representation and use of clinical practice guidelines. *Int J Med Inf*, 63(3), 147-167.
- Patel, V. L., Glaser, R., & Arocha, J. F. (2000). Cognition and expertise: acquisition of medical competence. *Clin Invest Med*, 23(4), 256-260.
- Schvaneveldt, R. W. (1990). *Pathfinder associative networks: studies in knowledge organization*. Norwood, New Jersey: ABLEX Publishing Corporation.

Running Title: COGNITIVE IMPACT OF INTERACTIVE MULTIMEDIA

Cognitive Impact of Interactive Multimedia: Comparing Impact of Diverse
Representational Strategies

Yanko Michea MD

School of Health Information Sciences

The University of Texas Health Science Center at Houston

Abstract

Purpose: There is not enough information to assess the impact of multimedia as cognitive tool to foster higher levels of understanding and learning. This pilot study analyzed the effect of Interactive Multimedia in learning a complex cognitive task such as control of the respiratory system during exercise. Method: A sample of volunteers was evaluated in order to assess learning using a pre and post test evaluation design. Volunteers were randomly assigned to any of three intervention styles: Static, Dynamic or Interactive content presentation. Subjects were also randomly assigned to one of two assessment strategies: 1. A Multiple Choice questionnaire was use to evaluate learning in three areas: system Components, Dynamics and Control rules. 2. Pathfinder Network Analysis was used to assess mental models change. Results: From a sample of 81 volunteers, 26 finished the whole evaluation (15 volunteers for Multiple Choice and 11 for Pathfinder Network analysis). The results from the Multiple Choice evaluation support the hypothesis that Interactive Multimedia is the best strategy to teach system's control rules. Pathfinder Network analysis did not show significant changes. Discussion: The data gathered during this pilot study allowed us to assess the feasibility of this kind of study, and to detect strong tendencies as were evidenced by the statistically significant differences in the group using the highly interactive application. The also data suggests that there could be architectural changes in conceptual maps associated with these educational interventions. Further research is going to be required to improve the quality of this assessment, increasing the generalizability of these findings.

Cognitive Impact of Interactive Multimedia: Comparing Impact of Diverse Representational Strategies

Introduction

Interactive Multimedia is playing an increasingly relevant role in health education innovation (Issenberg, Gordon, Gordon, Safford, & Hart, 2001; Karim & Qayumi, 1999; Letterie, 2003; Myers, Swan-Kreimeier, Wonderlich, Lancaster, & Mitchell, 2004; Schitteck, Mattheos, Lyon, & Attstrom, 2001). Educators have seen the enormous potential of this technology, investing time and resources in the development of technology-based education environments with diverse degree of success. In spite of this popularity, there isn't enough information to help us to understand these discrepancies. Further research is needed in order to understand the underlying cognitive processes fostered or triggered by different technology based interventions and evidence-based frameworks for the development of interactive multimedia for health education. This article presents the results of a pilot study to evaluate the cognitive impact of interactive multimedia in learning.

The goal of this project is to improve our knowledge about the most effective strategies to use interactive multimedia in education. As a test bed for our framework, we have chosen to evaluate the impact of Interactive Multimedia to support learning of complex dynamic systems. Respiratory Response to Exercise, a common physiology topic that is often quite difficult for students to master, has been selected as the topic for our Interactive Multimedia Application. Learning in this domain requires not only the

memorization of static elements or structures (system components) but also understanding of dynamic relationships (system dynamics), and integration of these changes with complex control systems and rules (system control). Interactive Multimedia, simulations and other multimedia materials should be especially well suited for learning these concepts. Our project contrasts the effect of less interactive representations, (static or animated) with a highly interactive learning environment. The evaluation assesses students' skills using multiple choice tests and conceptual mapping tools. The educational intervention and evaluation tools were developed using a theoretical and methodological framework based on evidence from educational, cognitive and information sciences.

Learning with Multimedia: Animations and Interactions

Is Multimedia Improving Learning?

Educators and Instructional Designers need to know if multimedia is effective as an educational aid. Current research has tried to answer this question using multiple strategies and with diverse degree of success. A fairly recent meta-analysis report (Liao, 1998), shows that in at least 69% of the published studies, multimedia learning environments had a positive effect when compared with traditional instruction. Multimedia has also shown a positive effect in the development of higher cognitive skills in science learning (Frear, 1999; Iding, 2000b; Moore, 2000). Analysis of the value of static graphic representations have supported its value for complex scientific information visualization (Iding, 2000a, 2000b). The use of animated representations of abstract

scientific concepts, has been related with an enhanced holistic understanding of the content (Blankenship & Dansereau, 2000; ChanLin, 1998; Nichols, Merkel, & Cordts, 1996; Spotts & Dwyer, 1996). Some suggest that interaction would enhance learning by allowing users to dynamically interact with the content, in a way that represents the dynamics of the process, thus improving their holistic understanding of the system (ChanLin, 1998; Mergendoller, 1997; Nichols et al., 1996), but there is no clear explanation of how this would be achieved, nor what learning processes could be supported by the interaction

The increasing interest in the holistic comprehension of scientific processes requires the integration of complex information sources. So far, traditional digital media has been effective in communicating extensive amounts of textual information and data. The current challenge is placed in the need for effective ways to facilitate the comprehension of global processes, of a system's working and rules. Animation contributes to generate a panoramic view of complex data sets and to understand how a system works. Interaction can contribute by increasing the understanding of the rules governing these dynamic systems.

Can Interactive Multimedia Improve Learning?

Current evaluation of a variety of programs with a diverse combination of animation and rich interaction indicates a variable degree of learning success (Blankenship & Dansereau, 2000; ChanLin, 1998; Liao, 1998; Mergendoller, 1997; Nichols et al., 1996; Spotts & Dwyer, 1996). Although overall success is not consistent, certain interactive applications are quite successful, including flight simulation programs to support pilot training, and games originally designed for entertainment (McFarlane,

Sparrowhawke, & Heald, 2002). The analysis of these successful interactive applications suggests an important role for representation style, as it constraints the interaction, mapping directly this constraints and the learning task, making it easy for the learner to take the information directly from the environment. This kind of interaction seems to be empowered by the flexibility of some learning environments that allow the student to test multiple solutions to the task, testing at the same time their own conceptual models of the problem space.

No current theoretical approach is sufficient

Various theoretical and pedagogical approaches have been sited in the design of educational multimedia, with focus on behavioral, social or cognitive issues involved in learning. For instance, the information processing theory (Bagui, 1998) and the theory of Dual Coding (A. Paivio, 1991; Allan Paivio, 1997) have strong support among instructional designers; this theory focus on the role of the information stimulus and its relationship with sensory and cognitive input channels. In this theoretical approach, a successful learning environment should balance information load and learners' processing capabilities. Newer approaches using computers to support generative activities have shown positive effects in the stimulation of metacognitive processes, and improving problem solving strategies (Azevedo, 2002; Clements & Nastasi, 1999; Hokanson & Hooper, 2000; Xiaodong, 2001). The use of interactive, inquiry-based learning environments has also successfully improved science learning for elementary, middle and high school students (Linn & Slotta, 2000).

Although these theories have contributed to the design and evaluation of interactive multimedia, current models fail to explain the observed inconsistencies in the

efficacy of multimedia in education. However, the relationship between content, tasks, and media has been extensively analyzed in cognitive science (Larkin & Simon, 1995; Scaife & Rogers, 1996; Jiajie Zhang, 1997), but the application of this knowledge in the design and evaluation of interactive educative materials has been insufficient.

Distributed Representation- From Cognitive Science to Training

Learning is a complex process that requires the simultaneous coordination of multiple variables involving the learner, the teaching agent, and the environment (Figure 6)S. To communicate a given concept, an external artifact must be created to represent the knowledge. The representation of the contents or knowledge can be verbal, visual, and/or digital (Schott & Driscoll, 1997). As the learner interacts with the representation in the context of a learning task (pedagogy), new knowledge is constructed. The introduction of technology and multimedia has created an explosion in the number of shapes that this external representation can take.

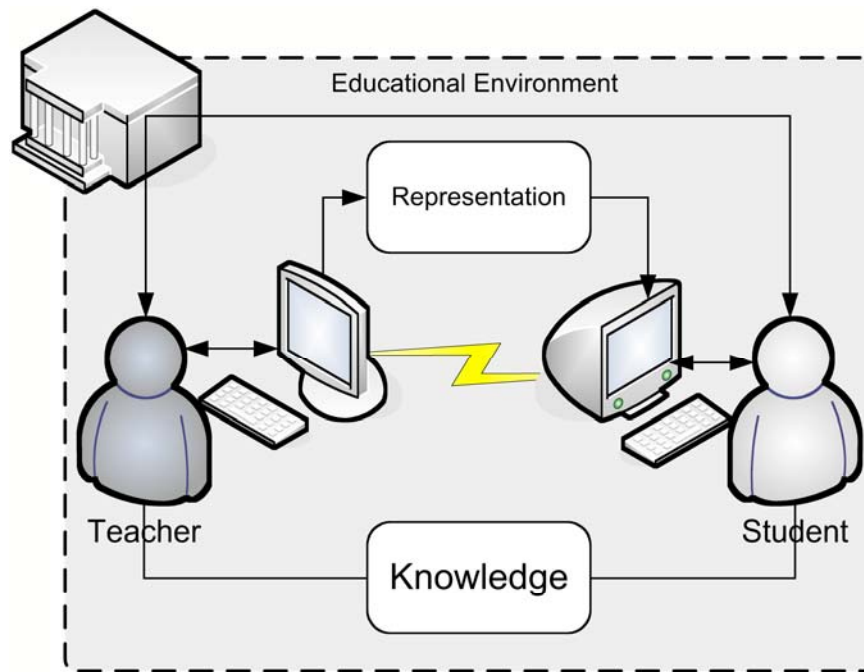


Figure 6

Learning Environment and Representations.

Distributed representation theories give us a detailed analysis of the relationship between content to be learned, its representation, and the underlying cognitive processes (Scaife & Rogers, 1996). Choosing the proper representation, so that the constraints on the representation match the described content and learning task, should minimize the cognitive work for the user (inference) and improve learning (Barwise & Etchemendy, 1996). For this project, we used a general analytic framework for external representations proposed by Zhang and Norman, leaders in the field of information representation. This theory says that the form of a representation determines "...what information can be perceived, what [cognitive] processes can be activated, and what structures can be discovered from the specific representation." (Jiajie Zhang, 1997). External representations can serve as cognitive aids to improve understanding, by anchoring and

structuring cognitive behavior, making information visible and sustainable, aiding processability by limiting abstraction, and through many other means (28).

This framework was originated in the analysis of the impact of information representation in problem solving strategies (Jiajie Zhang & Norman, 1994). Much is known about how information representation affects/supports various types of learning, and this is incorporated into our design framework. For instance, diagrams (Iding, 2000a) have been successfully used in identification, comparison and sequencing tasks. Series of images (multiples), organized in visual lists of objects or concepts can help viewers to analyze, compare, differentiate or decide (Tufte, 1997). Animations have been used to represent movement (Blankenship & Dansereau, 2000; Scaife & Rogers, 1996), and to illustrate complex structural, functional and procedural relationships among objects and events, and it has proven to be a positive aid to teach procedural information (ChanLin, 1998). Further research has extended the application of the theory to problem solving in dynamic complex environments (Chuah, Zhang, & Johnson, 2000; Jiajie Zhang, Johnson, & Lu, 2001) and to analyze the use of animated representations (Cheng, Lowe, & Scaife, 2001; Jones & Scaife, 1999, 2000; Scaife & Rogers, 1996).

We have applied the Distributed Representational Theory to encompass the design of Interactive Multimedia, shifting the focus to the task of learning, and from static to dynamic representations. We understand learning as the acquisition of new declarative and/or procedural knowledge. In technology supported learning, this process involves the interaction of the learner with a computer interface representing the strategies implemented to foster learning. The Resources Model (Wright, Fields, & Harrison, 2000) is useful to understand the process of interaction. In this recursive cycle,

the individual recognizes changes in the environment, and adjusts the actions according to the evaluation of the interface state. The perception and evaluation of the interaction is based on the user's goals. In order to successfully apply any media, it must at least be capable of representing this knowledge and the changes in a way that those changes can be easily interpreted in relation with a user's goals. Finally, the interface must also be able to represent the history of interactions that have taken place in the search of the desired outcome (Hutchins, D., & A., 1986; Wright et al., 2000). An ideal interface should be able to implement the educational strategies, also providing synchronous feedback of the state of the tasks involved. Successful content representations should be able to convey knowledge with the least amount of cognitive noise from the interaction with the interface.

Systems Theory and Learning

Systems' theory, defines the main characteristics of dynamic system as the components, constraints and rules organizing sets of related elements (Johansen, 1994). This theoretical and methodological approach has helped science to describe and model sets of relationships in many complex systems such as biological systems, ecosystems, geological processes, and so forth. Many systems organize their behavior according to complex feedback loops that the learner must holistically understand to recognize and describe the patterns of the system, and to predict the future states of the system. In our framework, we used systems theory to categorize the types of educational content into three main sections: definition of components (declarative knowledge, dynamics (changes and their parameters), and the rules (feedback loops, complex interactive learning content).

Learning Taxonomy

The most widely used taxonomy of learning was described by Bloom and his colleagues (1956). This taxonomy allows us to categorize types of educational objectives for the cognitive domain, for things such as declarative knowledge (Reigeluth, 1999). The six hierarchical levels defined in this taxonomy have set a common language for educators and instructional designers.

Gagne’s taxonomy also has wide acceptance in instructional design and offers a good cognitive layout between Bloom’s Taxonomy and System Theory. The Verbal Information stage of this taxonomy asks the learner to state or tell facts or events. The second level, Intellectual Skills, requires the subject to operate within the domain using symbols. Finally, the Cognitive Strategies level is focused in the subject’s higher order capabilities to plan and coordinate actions within the domain. Table 1 summarizes the links between these three approaches.

Table 10.
Instructional taxonomies

Bloom	Gagne	System Theory
Knowledge	Verbal Information	Components
Comprehension		
Application	Intellectual Skill	Dynamics
Analysis	Cognitive Strategy	

Synthesis

Evaluation

Control

Research Hypothesis

We hypothesize that different media, like text, graphs, animations or interactivities should impact learning differently, and that this specificity is related with the characteristics of the knowledge to be learned. From a learning standpoint, the learning task can be differentiated depending on its cognitive complexity and mastery level required. From a systemic standpoint, this knowledge is associated with well defined system description levels. Finally, this system levels can be associated with the specific representation styles and strategies. Traditionally, static representations have proved to be successful tools to teach rote facts, the same way that animation seems to be a good strategy to help students to learn about dynamic relationships. The purpose of this project was to test the impact of Interactive Multimedia as strategic media to learn higher levels of complexity such as the control rules of a biological system by using interaction to allow students to manipulate, test and see the power of the control system.

Research Question

- Given a set of informationally equivalent educational applications, can we measure the impact of different representations styles in learning?
- Is Interactive Multimedia the most effective way of representing system rules?

Method

In this study we attempted to assess the effect of different representation styles over learning. We were specifically interested on how Interactive Multimedia can affect learning system's control rules, and in comparing this effect with other traditional representations, such as text and static pictures or animation. We focused the analysis in the evaluation of changes in knowledge about the system's control rules.

For that purpose we developed three informationally equivalent applications, so that, the content of each of these representations is equivalent, while we changed the way that system's control rules were represented:

Static Representation: Text is used to present an explanation of the control of the system and the different variables participating of the process. A picture represents the different states of the system.

Animation: In this representation we kept the text, and changed the static picture for an animation of the same process in a way that the student could gradually observe the changes over time. The Linear animation represents sequence of events in a linear argument. All events have a defined outcome that can be reviewed forwards or backwards as many times as the user wants. The closest example is the controls you have on your VCR.

Interactive Multimedia: The third representation replaces the animation, with an interactive application capable of changing with the user actions. The user can interact

with the system playing the role of the control system. This implies that the learner is going to be in control of the rules controlling the dynamics of the system. The interaction in this case is more complex, and allows the user to test his pre-conceptions, experimentation with alternative rules and discovery of the rules of the system.

Table 11:

Information Representation in each activity

		Components	Dynamics	Control
Intervention 1	Textbook	Text&Graphics	Animation & Text	Text&Graphics
Intervention 2	Animation	Text&Graphics	Animation & Text	Animation & Text
Intervention 3	Interactive	Text&Graphics	Animation & Text	Interaction & Text

Learning Activity

We chose to use the respiratory control system as our test content. Previous research has found highly prevalent difficulties in students ability to predict the respiratory system behavior with exercise or physiologically equivalent situations (J. Michael, 2002; J. A. Michael, 1998; J. A. Michael et al., 1999). The module includes a review of the anatomy, and normal physiology of the system, and a section specifically dedicated to the study of the physiological response to exercise. After completing the Interactive Multimedia, we expect the student to improve his/her knowledge about the control of the system that governs the respiratory system during exercise.

Respiratory Volume/Frequency Control System

The classic example of a control system is a thermostat. In control systems, you can recognize three levels of organization. The first level corresponds to the Components, the static structures within the system, like the walls of a room, the thermometer and the heating device. The second level, the Dynamics, is composed by structures like switches, machines or other elements with predetermined movements. The third level is the Control system, is the level where all the aforementioned components and dynamics are coordinated. The comprehension of the role of this level requires the holistic integration of the other levels with the variables affecting the system. This level usually presents a major cognitive challenge and it is the one that we have selected to test using different representation styles.

Table 12

Systemic analysis of the Respiratory Response to Exercise module.

Level	Example	Representation
Components	Anatomic Structures (bones, muscles, lungs, etc.)	Text and Pictures
Dynamics	Changes in tidal volume, muscle activity, etc.	Text and Animation
Control	Coordination of Components and Dynamics with environment and rules.	Text and Interaction*

*Note: For our experiment, the sample subjects were randomly assigned to one of three activities, each with a different kind of interaction with the control subsystem.

Our objective was to test the power of Interactive Multimedia to represent and teach these system rules. The critical piece of representation is the mapping of the control elements (rules) of the system onto the interaction. The other system components, the object components and constraints were controlled, keeping constant the representation elements selected for each content element.

A Multilevel Learner-Centered Design Framework

The design of effective learner-centered educational software requires a solid design framework that is geared towards the learning process. The multilevel design framework (J. Zhang, Patel, Johnson, Malin, & Smith, 2002) developed by Jiajie Zhang and colleagues at the University of Texas, School of Health Information Sciences is based on research in cognitive science, human-computer interaction, interface design and information visualization theories, and was originally developed as a general framework that we adapted to the task of designing educational Interactive Multimedia.

Educational Module

We developed an online educational module in two languages (English and Spanish). The activity was divided into four sections: Introduction, Functional Anatomy, Ventilation Physiology, and Ventilation & Exercise (Figure 7). The first section introduced the activity, its objectives and the main navigation features. The Functional Anatomy section was designed to review the anatomy of the respiratory system and the structures involved in ventilation physiology. The Ventilation Physiology Section was developed to review the physiology of the respiratory system while resting and during exercise. Most of the knowledge in these sections should be used as a review of content

that the student should have previously known. The final section: Ventilation & Exercise, explained the changes occurring in the respiratory system during exercise; three alternative representations were developed to change the way control rules were represented, as it was previously discussed: Interactive Multimedia, Animation or as a picture.

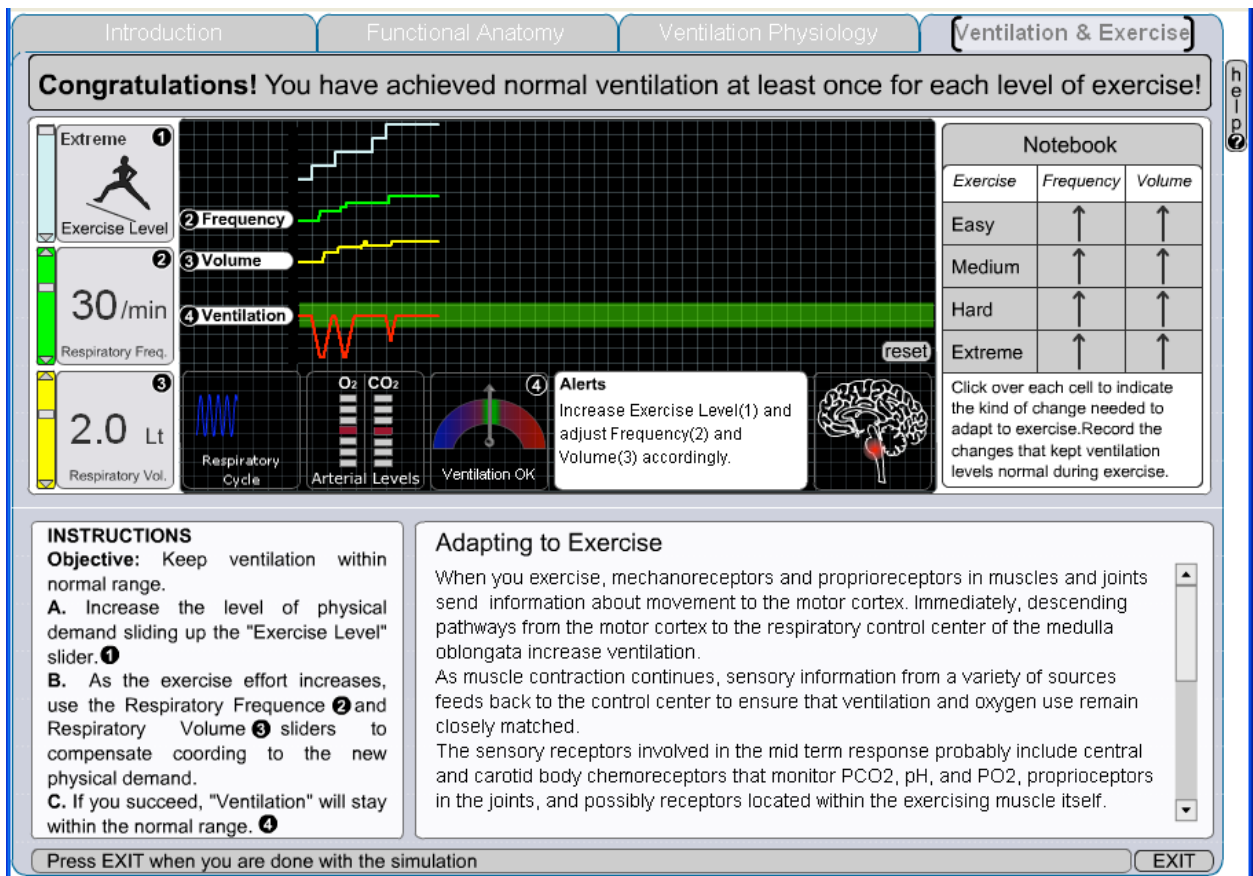


Figure 7
Educational Module Interface

Learning Evaluation

Learning was assessed using two strategies: Multiple Choice and Pathfinder Network analysis. Each volunteer was randomly assigned to one of these evaluation strategies. With the help of content experts we developed a set of questions to assess

student learning at different levels. One set of questions were developed to assess the students' capability of recognizing the components of the system: Multiple choice questions where the student should recognize diverse anatomical structures. A second set of questions was designed to evaluate their understanding of the Dynamics of the system: The student was asked to predict changes in the system during or after exercise. The third group of questions was specifically designed to assess their knowledge of the Control of the system: Recognition of the role of the control systems and its coordination during exercise. The test was administered to a randomly assigned group of volunteers as a set of 24 questions pre and post intervention.

The second evaluation strategy was designed to analyze changes in the students' conceptual structure before and after the instructional modules. This evaluation was based on previous research on quantitative concept mapping (McGaghie, McCrimmon, Mitchell, Thompson, & Ravitch, 2000; McGaghie, McCrimmon, Thompson, Ravitch, & Mitchell, 2000). According with this research, students' conceptual maps change as they learn, and that change is associated with changes in the internal consistence of the model (coherence), and by increased levels of similarity with models derived from experts. In order to develop such models, the learner is asked to determine the degree of relatedness of concepts representing the domain. This list of concepts was developed with the collaboration of two domain experts, who helped to define a list of 14 key concepts. The combination of these concepts generated a set of 92 possible relationships. In order to avoid fatigue of the volunteer responders, the list was reviewed in order to keep the most meaningful relationships for the topic. The eliminated relationships corresponded to redundant relationships, and relations with a minimum degree of functional association.

The final list was composed by 52 conceptual relationships that each volunteer in the Pathfinder Network group was asked to grade as pre and post test.

Experimental Design

The measurements were done as pretest-posttest evaluations for each group of students (Campbell & Stanley, 1963). All data collection was computer-based and the information was synchronously stored in a database. Besides pre and post test evaluation data, demographics and time spent in the activity was also captured in the database.

Each participant was randomly assigned to an evaluation strategy: Multiple choice questionnaire (Knowledge Evaluation) or Pathfinder network analysis (Concept Mapping). Then the students were randomly assigned to any of the intervention styles: Static, Animation, or Interactive (Table 13).

Table 13

Experimental Design: Groups

	Interactive	Animation	Static
Multiple Choice	X	X	X
Pathfinder Network	X	X	X

Data Analysis

The dataset was divided in two groups depending on the evaluation strategy used: Multiple Choice or Pathfinder Network Analysis. The Multiple Choice results analysis

included the evaluation of correctness of the answers in the pre and post tests, and the calculation of the rate of improvement over the pretest. These results were correlated with the intervention group and with time spent in the activity. Significance levels for the score differences were calculated using Kruskal-Wallis test. Significance levels for improvement ratio were determined with One-way ANOVA test. Subscales change analysis was done using two-way ANOVA procedures. Finally, time spent each group activity was analyzed using unpaired t-test as well as correlated with final scores using linear regression procedures.

In order to proceed with the Pathfinder Network analysis, the data for each participant was independently processed with KNOT ("KNOT," 2004), software specifically developed to perform these analysis. The outcome of this process was a coherence value for each network (internal consistency of the data), a conceptual network, and a definition (position and distance) of the existing links between each of the concepts in the network. Coherence and similarity data were compared per intervention group (one-way ANOVA statistics), and grouped together (pre and post unpaired t-test statistic). We also correlated time with each one of these two variables using linear regression analysis. Changes in the number of links per node pre and post and for each category of relationship were also analyzed using two-way ANOVA (Friedman).

Participants

Student volunteers were recruited in two Universities in Chile (Los Andes University and Pontifical catholic University), and at the Texas Medical Center at Houston. The students were required to have finished at least one physiology course. The activity module and evaluation instruments were available online, and three inclusion

criteria were required for the analysis of the data: the volunteer should finish pre and post evaluations, the user should spend at least 20 minutes within the learning environment, and the Pathfinder Network analysis should have a coherence index of at least 0.2. The activities were developed in English and Spanish, and the participant was free to choose his/her preferred language for the activity.

The learners in our research were equivalent to juniors in college within a science track who have not yet taken physiology classes covering respiratory or cardiovascular systems. Previous knowledge was controlled with a pre-test evaluation. Gender, age, education, and language preference were assessed in our pretest evaluation. After a pre-test evaluation each subject was randomly assigned to one of the interventions. Once the intervention is finished, each student completed the post-test (Campbell & Stanley, 1963).

Results

Participants

A total of 81 subjects volunteered for this study. Most of the participants were Spanish speakers, Male, undergraduate students (see Table 14). Demographic distribution among the different experimental groups was analyzed, without finding any statistically significant difference. From this group, 31 (38.27%) volunteers successfully finished the three sections of the activity, while another 31 (38.27%) completed just the pretest, and 19 (23.46%) did not finished any of the sections. The statistical analysis of the demographic characteristics of these three groups did not show any significant difference.

We also compared the results from the pre-test evaluation for Pathfinder network coherence between the complete and incomplete groups without significant differences. The comparison of the results on the Multiple Choice group showed a mean difference of 3 points in favor of the incomplete group (Incomplete $M= 17.93$ points; Complete $M = 14.83$; $P=0.02$).

Table 14Participants Demographics ($N=81$)

Language	English (%)	Spanish (%)	
	24 (29.63)	57 (55.56)	
Gender	Male (%)	Female (%)	
	45 (55.56)	36 (44.44)	
Degree	Undergrad (%)	Graduate (%)	Postgraduate (%)
	59 (72.84)	16 (19.75)	6 (7.41)

Multiple Choice Data Analysis

A total of 23 volunteers finished the activities in this evaluation modality. From this sample, 8 participants finished the activity in less than 20 minutes so their data was discarded of further analysis. The remaining 15 volunteers took an average 36 minutes to finish the activity ($M=36.55$, $SD=12.4$). Once the data from the 8 aforementioned

subjects was removed from the analysis, there was no significant correlation between time spent in the activity and final score. Overall, there were statistically significant differences between the results of the pre and post evaluations (Pretest $M=16$; Posttest $M=20.53$; $P=0.008$). Then we analyzed the changes presented between the three kinds of intervention looking for differences in the post test evaluation or scores changes per individual. On average, the results independently from the question domain, do not differ across the different interventions.

Finally, we analyzed the effect of intervention style over each evaluation subscale: Components, Dynamics and Control Systems question. This evaluation showed significant differences for dynamics and control rules learning related with intervention style (see Table 15). These differences are not observed for learning of the system components.

Table 15

Effect of Interventions over Score. Mean by Multiple Choice questions subscale.

Rule Presentation	Components (SD)	Dynamics (SD)	Control (SD)	Average (SD)
Interactive (N=4)	3.0 (3.6)	5.5 (1.9)	1.25 (1.9)	2.1 (6.7)
Animated (N=5)	0.8 (2.9)	0.4 (2.9)	1.8 (0.8)	1.7 (5.6)
Static (N=6)	3.3 (3.9)	2.2 (1.2)	-0.3 (1.0)	3.0 (5.8)

	NS	$P=0.02$	$P=0.02$	NS
--	----	----------	----------	----

From the initial sample of Pathfinder Network volunteers, 11 were able to finish the activity. In this group four subjects had to be excluded of the data analysis given the low coherence of the networks (Coherence <0.2). In the remaining 7 participants, the overall changes in coherence between pretest and posttest evaluations were not significant for this sample. The networks were then compared with networks produced from data from three different experts, without any significant change between pretest and posttest evaluations. These results were consistent across and between the networks for the different experimental interventions. The network architecture show some tendency towards a more streamlined design, represented by a tendency to decrease the number of links per network between the pre and post evaluations, but this difference was not statistically significant (Pre $M=19.6$ $SD=3.26$; Post $M=18.3$ $SD=5.47$).

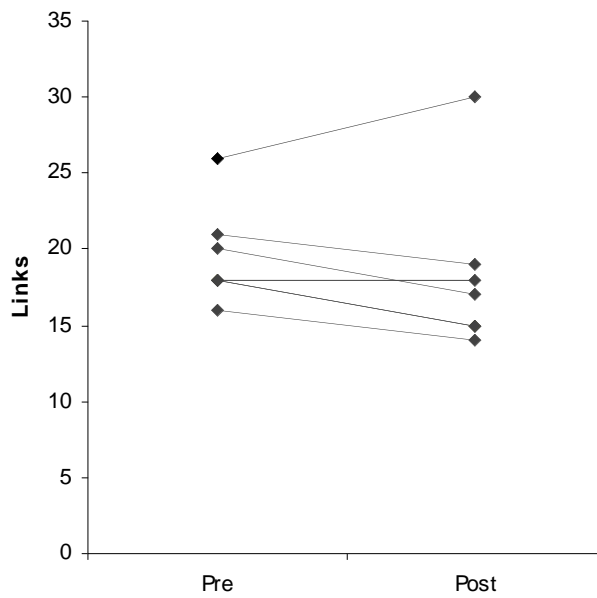


Figure 8

Pathfinder Network total links per map

In order to understand if there was any effect on the way control system nodes change with the intervention, we analyzed the number of links that each one of the nodes representing control system structures were receiving (see Figure 9). This analysis shows a significant increase in the number of links present (Pre $M=17.86$ $SD=3.53$; Post $M=22.86$ $SD=5.87$; $P=0.02$).

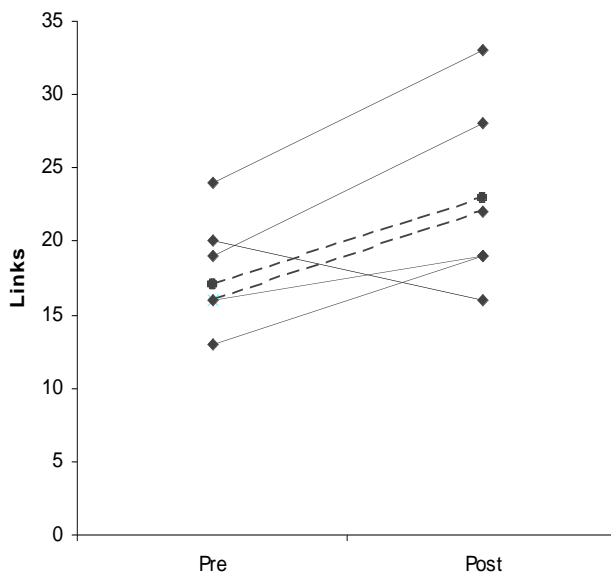


Figure 9

Pathfinder Network links from control systems

Discussion

Does Interactive Multimedia affect learning? The results of this pilot study showed interesting results supporting the hypothesis of a distinctive effect of interactive materials over learning. The evaluation of the Multiple Choice evaluation suggested that the application successfully increased knowledge on the three intervention groups. As we hypothesized, using a static representation of the control rules was not enough to produce changes in the students' scores on this topic. On the other hand, using Interactive Multimedia was successfully related with changes in these scores. Surprisingly, the results found in the evaluation of dynamics of the system were different of what we expected: given that all the applications used the same kind of representation of the system dynamics, we should have at least the same results between the three

interventions; eventually we could argue that the use of Interactive Multimedia could have a positive result over the understanding of such dynamics, but we are not capable of offering a good explanation of the lower results in one of the groups, besides that this must be an artifact secondary to the small sample size.

The second evaluation strategy used a likert scale tool to derive a conceptual network of the respiratory physiology system. Unfortunately, this group was too small in order to find significant differences between intervention groups. In previously reported experiences, learning has been usually associated with increased coherence or similarity with experts' networks (McGaghie, McCrimmon, Mitchell et al., 2000; McGaghie, McCrimmon, Thompson et al., 2000). In our study there were not significant differences in these variables. Nevertheless, we were able to observe some differences in the number of links within the networks. Research evidence evaluating mental models' change across different levels of expertise (Patel, Arocha, Diermeier, How, & Mottur-Pilson, 2001) has suggested that mental models tend to become more simple or streamlined as expertise increases. We believe that the observation of link behavior can be explained as a change associated with this learning process. On the other hand the significant increase in the number of connections of concepts associated with control systems could represent increased awareness of the role of these control processes in the physiologic response to exercise. Further research with bigger sample size is required to explore this hypothesis.

The goal of this project was to analyze the impact of Interactive Multimedia in learning using a real word scenario and calling a wide diversity of volunteers to participate. Even though it was an excellent opportunity to assess educational problems in a wide variety of cultural environments, it also introduced new uncontrolled variables

related with culture, motivation and access to technology. Our informal evaluation of the causes of high number of incomplete evaluations showed a high prevalence of technical problems among the distant students. It was especially relevant, given the length of the activity issues associated with reliability of Internet connection. Cultural and motivational issues also affected the commitment of the volunteers to the activity: most of the Spanish speaking students in our sample were used to activities with direct supervision, and this experiment was presented as a volunteer, unsupervised activity. We believe that this change in the educational scenario was also an important variable playing some role in the high drop out rate. In spite of these problems, it was interesting to observe that the educational topic selected presented very similar characteristics in otherwise different populations. The results of this pilot study prove the feasibility of this kind of research and also give us information about the issues to consider for future projects.

In order to increase the validity and reliability of the observations made during this study, the next step should be to retest our hypothesis in a more controlled scenario and population. Using a more rigorous experimental setting, especially controlling most technical and connectivity issue should substantially improve the quality of our results. This should also give us the opportunity of offering a more structured scenario that should directly impact the number of dropouts during the experiment. Accounting for students' motivational issues needs the coordination of multiple strategies such as reimbursing volunteers, or including these materials as part of the curricular activities of students taking part of a physiology class.

The results from this pilot study strongly support a role for Interactive Multimedia as cognitive tool. The uniqueness of this tool does not seem to be in the quantity of knowledge that is capable to convey, but more strongly in its role promoting the development of holistic comprehension of the rules of complex systems. We chose to test this assumption in a very specific domain, but there are many other educational problems that require this kind of skill. The development of tools capable of interacting with the user conceptual frameworks will require a good comprehension of the components, dynamics and control processes and the correct matching of these with appropriate representation media and strategies. Consistently use of an evidence based design and development framework should not be constrained to experimental scenarios, but embedded in traditional practice as this strategy promises substantial improvements in the consistency and quality of educational outcomes. Further research evaluating the role of representations and testing more reliable methods and strategies for the development of these tools will be required. The success of this kind of research will be instrumental in the development of new paradigms for the future of technology-empowered education.

References

- Azevedo, R. (2002). Beyond Intelligent tutoring systems: Using computers as METAcognitive tools to enhance learning. *Instructional Science* (30), 31-45.
- Bagui, S. (1998). Reasons for increased learning using multimedia. *Journal of Education Multimedia and Hypermedia*, 7(1), 3-18.

- Barwise, J., & Etchemendy, J. (1996). Visual information and valid reasoning. In G. Allwein & J. Barwise (Eds.), *Logical reasoning with diagrams* (pp. 3-25). New York: Oxford University Press.
- Blankenship, J., & Dansereau, D. (2000). The effect of animated node-link displays on information recall. *The Journal of Experimental Education*, 68(4), 293-308.
- Campbell, D. T., & Stanley, J. C. (1963). *Experimental and Quasi-Experimental Designs for Research*. Chicago: Rand McNally College Publishing Company.
- ChanLin, L.-j. (1998). Animation to teach students of different knowledge levels. *Journal of Instructional Psychology*, 25(3), 166-175.
- Cheng, P., Lowe, R., & Scaife, M. (2001). Cognitive science approaches to diagram use. *Artificial Intelligence Review*, 15(1/2), 79-94.
- Chuah, J., Zhang, J., & Johnson, T. R. (2000). *The representational effect in complex systems: a distributed representation approach*. Paper presented at the 22th Annual Conference of the Cognitive Science Society, Hillsdale, NJ.
- Clements, D., & Nastasi, B. (1999). Metacognition, learning, and educational computer environments. *Information Technology in Childhood Education*, 1999, 5-38.
- Frear, V. (1999). Does interactive multimedia promote achievement and higher level thinking skills for today's science students? *British Journal of Educational Technology*, 30(4), 323-329.

- Hokanson, B., & Hooper, S. (2000). Computers as cognitive media: examining the potential of computers in education. *Computers in Human Behavior* (16), 537-552.
- Hutchins, E. L., D., H. J., & A., N. D. (1986). Direct Manipulation Interfaces. In N. D. A. & D. S. W. (Eds.), *User Centered System Design* (pp. 87-124). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Iding, M. (2000a). Can strategies facilitate learning from illustrated science texts? *International Journal of Instructional Media*, 27(3), 289-301.
- Iding, M. (2000b). Is seeing believing? Features of effective multimedia for learning science. *International Journal of Instructional Media*, 27(4), 403-415.
- Issenberg, S. B., Gordon, M. S., Gordon, D. L., Safford, R. E., & Hart, I. R. (2001). Simulation and new learning technologies. *Med Teach*, 23(1), 16-23.
- Johansen, O. (1994). El enfoque de los sistemas. In L. Noriega (Ed.), *Introducción a la Teoría General de Sistemas*. Balderas, Mexico: Limusa Noriega.
- Jones, S., & Scaife, M. (1999). *Diagram Representation: A Comparison of Animated and Static Formats*. Paper presented at the ED-MEDIA 99: World Conference on Educational Multimedia, Hypermedia and Telecommunications, Seattle.
- Jones, S., & Scaife, M. (2000). Animated Diagrams: An investigation into the cognitive effects of using animation to illustrate dynamic processes. *Lecture Notes in Artificial Intelligence, Theory & Applications of Diagrams* (1889), 231-244.

- Karim, A., & Qayumi, T. (1999). Computer-assisted learning: cyberPatient--a step in the future of surgical education. *J Invest Surg*, 12(6), 307-317.
- KNOT. (2004). Gilbert, AZ: Interlink Inc.
- Larkin, J., & Simon, H. (1995). Why a diagram is (sometimes) worth ten thousand words. In J. Glasgow, N. Hari Narayanan & B. Chandras Karan (Eds.), *Diagrammatic Reasoning*. Cambridge: MIT Press.
- Letterie, G. S. (2003). Medical education as a science: the quality of evidence for computer-assisted instruction. *Am J Obstet Gynecol*, 188(3), 849-853.
- Liao, Y.-k. (1998). Effects of hypermedia versus traditional instruction on students' achievement: a meta-analysis. *Journal of Research on Computing in Education*, 30(4), 341-359.
- Linn, M., & Slotta, J. (2000). WISE Science. *Educational Leadership*, 2000(October), 29-32.
- McFarlane, A., Sparrowhawke, A., & Heald, Y. (2002). *Report on the educational use of games*. Cambridge: TEEM.
- McGaghie, W. C., McCrimmon, D. R., Mitchell, G., Thompson, J. A., & Ravitch, M. M. (2000). Quantitative concept mapping in pulmonary physiology: comparison of student and faculty knowledge structures. *Adv Physiol Educ*, 23(1), 72-81.

- McGaghie, W. C., McCrimmon, D. R., Thompson, J. A., Ravitch, M. M., & Mitchell, G. (2000). Medical and veterinary students' structural knowledge of pulmonary physiology concepts. *Acad Med*, 75(4), 362-368.
- Mergendoller, J. (1997). Sifting the hype: what research says about technology and learning. *Principal*, 76(Jan 1997), 12-14.
- Michael, J. (2002). Misconceptions-what students think they know. *Adv Physiol Educ*, 26(1), 5-6.
- Michael, J. A. (1998). Students' misconceptions about perceived physiological responses. *Am J Physiol*, 274(Adv. Physiol. Educ. 19), S90-98.
- Michael, J. A., Richardson, D., Rovick, A., Modell, H., Bruce, D., Horwitz, B., et al. (1999). Undergraduate students' misconceptions about respiratory physiology. *Am J Physiol*, 277(Adv. Physiol. Educ. 22), S127-135.
- Moore, D. (2000). A framework for using multimedia within argumentation systems. *Journal of Education Multimedia and Hypermedia*, 9(2), 83-98.
- Myers, T., Swan-Kreimeier, L., Wonderlich, S., Lancaster, K., & Mitchell, J. E. (2004). The Use of Alternative Delivery Systems and New Technologies in the Treatment of Patient with Eating Disorders. *Int J Eat Disord*, 36(2), 123-143.
- Nichols, C., Merkel, S., & Cordts, M. (1996). The effect of computer animation on students understanding of microbiology. *Journal of Research on Computing in Education*, 28(Spring), 359-371.

- Paivio, A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology*(45), 255-287.
- Paivio, A. (1997). *Mental representations: A dual-coding approach*: Oxford Sciences Publications.
- Patel, V. L., Arocha, J. F., Diermeier, M., How, J., & Mottur-Pilson, C. (2001). Cognitive psychological studies of representation and use of clinical practice guidelines. *Int J Med Inf*, 63(3), 147-167.
- Reigeluth, C. (1999). What is Instructional-Design Theory and How Is It Changing? In C. Reigeluth (Ed.), *Instructional-Design Theories and Models. A New Paradigm of Instructional Theory* (Vol. 2, pp. 5-29). Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers.
- Scaife, M., & Rogers, Y. (1996). External cognition: how do graphical representations work? *Int. J. Human-Computer Studies*, 45, 185-213.
- Schitteck, M., Mattheos, N., Lyon, H. C., & Attstrom, R. (2001). Computer assisted learning. A review. *Eur J Dent Educ*, 5(3), 93-100.
- Schott, F., & Driscoll, M. (1997). On the Architectonics of Instructional Theory. In R. Tennyson, F. Schott, N. Seel & S. Dijkstra (Eds.), *Instructional Design. International Perspective. Volume 1: Theory, Research, and Models* (Vol. 1, pp. 135-173). Mahwah, New Jersey: Lawrence Erlbaum Associates.

- Spotts, J., & Dwyer, F. (1996). The effect of computer-generated animation on student achievement of different types of educational objectives. *International Journal of Instructional Media*, 23(4), 365-375.
- Tufte, E. (1997). Multiples in space and time. In E. Tufte (Ed.), *Visual Explanations. Images and quantities, evidence and narrative* (pp. 104-119). Cheshire, Connecticut: Graphic Press.
- Wright, P., Fields, R., & Harrison, M. (2000). Analyzing human-computer interaction in distributed cognition: the resources model. *Human-Computer Interaction*, 15, 1-41.
- Xiaodong, L. (2001). Designing metacognitive activities. *Educational Technology Research and Development*, 49(2), 23-40.
- Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science*, 21(2), 179-217.
- Zhang, J., Johnson, T. R., & Lu, G. (2001). *The impact of representational formats on a dynamic decision making task*. Paper presented at the 3rd International Conference of Cognitive Science.
- Zhang, J., & Norman, D. A. (1994). Representations in distributed cognitive tasks. *Cognitive Science*(18), 87-122.

Zhang, J., Patel, V. L., Johnson, K. A., Malin, J., & Smith, J. W. (2002). Designing human-centered distributed information systems. *IEEE Intelligent Systems*, 17(5), 42-47.

Final Remarks

The goal of this project was to increase our knowledge about the cognitive impact of multimedia in education. Given the wide scope of this area, the project was focused in learning systems' control rules, one of the most challenging cognitive tasks, and in the use of a very promising strategy: interactive multimedia.

In order to increase the reliability of the results, important theoretical, design, development and evaluation issues needed to be addressed. The theoretical framework developed, based in the integration of cognitive, information and learning theories was fundamental for the establishment of a coherent basis for the rest of the project. The integration of multiple theoretical sources seems to be especially critical in this domain, given the multiplicity of variables involved in the process of developing successful technology-based educational environments. Coherent theoretical models like the one developed for this project should be able to organize design, development and evaluation in a sound manner, allowing substantial feedback and improvement and retesting. The results of this iterative process should be able to improve not only the developed educational materials, but also the theoretical model and the associated methods.

These days, there are multiple design and development frameworks available for instructional designers and software developers. Most of these frameworks have a pragmatic focus, designed more to improve the workflow than to explain and improve the impact of these materials. The User Centered Multilayer approach was adapted to the educational environment and coherently matched with our theoretical framework. As part of this framework, a user centered evaluation framework was implemented as part of the

design and development process. The product of this process greatly improved user satisfaction and usability of the learning environment, improving the final user learning experience.

The evaluation of learning outcomes represented a major challenge for this project. Traditional methodologies have been able to measure behavioral outcomes that represent learning, but the value of such measures as reflection of meaningful learning is still under discussion. On the other hand, verbal elicitation protocols, like Think-aloud techniques offer more reliable measures of higher order cognitive change, but can hardly be applied to wide population or in a distant learning scenario. New techniques, using conceptual proximity data solve that problem, but there was scarce information about the relationship between mental or conceptual models derived using any of these two methods. In order to fill that gap, a within subject comparison of the results of these methods supported the idea that proximity data and models derived from them, using Pathfinder Network Analysis, were specific enough to be applied in the evaluation of learning associated changes in conceptual models, even though the low sensitivity of the method needs to be considered in the interpretation of any result.

Does Interactive Multimedia Improve Learning?

In our research there is evidence suggesting that Interactive Multimedia is capable of supporting learning in a more effective way than other less interactive media. This effect can be explained by the existing mapping between the interaction and the control rules in the system. Even more, this effect was not restricted to this kind of learning, but also with improved learning of systems' dynamics. Given the limitations of our study,

further research is going to be required in order to corroborate these findings and to improve our assessment of changes in the structure of the students' mental models.

The theoretical and methodological framework developed during this project can be used in future research in order to improve our understanding of the phenomena associated with learning complex systems. Just recently cognitive and information sciences have started being integrated into educational research. The results of this project prove that the contribution of these sciences in the understanding of the process and in the development of the new strategies for the future of technology-based education is promising. The results of such research efforts should guide our path towards new, more effective education.