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Cognitively Informed Multimedia Interface Design

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ABSTRACT

Multimedia systems offer interface designers the flexibility they require to build complex modules that are better informed of user expectations. However, to date the effort made towards this goal has in general ignored the replicable statistically stable findings of a relatively novel field of research; namely Cognitive Learning Theory. This paper presents an alignment map that shows how particular areas of the field may benefit specific design questions that arise during multimedia interface design. This is then applied as a case study that is evaluated to reveal that student made statistically significant improvements in their test levels. Results indicate that since learning requires cognitive processing either during the acquisition of learned materials, mentally processing it or keeping it in memory, then it is susceptible to cognitive traits that appear in similar cognitive tasks that form part of cognitive science research.

INTRODUCTION

The rich contributions made in the field of human computer interaction (HCI) have played a pivotal role in shifting the attention of the industry to the interaction between users and computers (Myers, 1998). However, technologies that include hypertext, multimedia and manipulation of graphical objects were designed and presented to the users without referring to critical findings made in the field of cognitive psychology. These findings allow designers of multimedia educational systems to present knowledge in a fashion that would optimize learning.

BACKGROUND

The long history of human computer interaction (HCI) has witnessed many successes represented in insightful research that finds its way to users' desktops. The field influences the means through which users interact with computers: from the introduction of the mouse (English et al, 1967) and applications for text editing (Meyrowitz & Van Dam, 1982) to comparatively recent areas of research involving multimedia systems (Yahaya & Sharifuddin, 2000).

Learning is an activity that requires different degrees of cognitive processing. HCI research recognized the existence of diversity in learning styles (Holt & Solomon, 1996) and devoted much time and effort towards this goal. However, Ayre and Nafalski (2000) report that the term "learning styles" is not always interpreted the same way and were able to offer two major interpretations. The first group believes that learning styles emerge from personality differences, life experiences and student learning goals, while the second group believes it refers to the way students shape their learning method to accommodate teacher expectations as when they follow rote learning when teachers expect it.

The first interpretation includes in part a form of individual differences but does not explicitly link them to individual cognitive differences which in turn caused researchers more ambiguities as to interpreting the different types of learning styles. In fact, these differences in interpretations caused Stahl (1999) to publish a critique where he cites five review papers that unite in concluding the lack of sufficient evident to support the claim that accommodating learning styles help improve children's learning when acquiring the skill to read. He criticized Carbo's reading style inventory and Dunn & Dunn learning inventory because of their reliance on self-report to identify different learning styles of students which in turn results in very low replication reliability.

These criticisms are positive in that they indicate a requirement to base definitions on formal replicable theory. A candidate for this is cognitive learning theory (CLT) represents the part of cognitive science that focuses on the study of how people learn the information presented to them and how they internally represent the concepts mentally in addition to the cognitive load that is endured during the learning process of the concepts.

Some of the attempts that were made to take advantage of the knowledge gained in the field include Jonassen (1991), van Jooligan (1999), and Ghaoui & Janvier (2004).

Jonassen (1991) advocates the constructivist approach to learning where students are given several tools to help them perform their computation or externally represent text they are expected to remember. This allows them to focus on the learning task at hand. He adopts the assumption originally proposed by Lajoie & Derry (1993) and Derry (1990) that computers fill the role of cognitive extensions by performing tasks to support basic thinking requirements such as calculating or holding text in memory, and thus allowed computers to be labeled as "cognitive tools". Jonassen's (1991) central claim is that these tools are offered to students to lower the cognitive load imposed during the learning process, which in turn allows them to learn by experimentation and discovery.

Van Jooligan (1999) takes this concept a step further by proposing an environment that allows students to hypothesize and pursue the consequences of their hypotheses. He did this through utilizing several windows in the same educational system. The system was composed of two main modules: the first supports the hypothesis formation step by providing menus to guide the process; the second provides a formatted presentation of experiments already tested and their results in a structured manner. They also added intelligent support to the system by providing feedback to students to guide their hypothesis formation approach.

Ghaoui and Janvier (2004) presented a two-part system. The first part identified the various personality types while the second had either an interactive or non-interactive interface. They report an increase in memory retention from 63.57% to 71.09% that occurred for the students using the interactive interface. They also provided a description of the learning style preferences for the students tested which exhibited particular trends but these were not analyzed in detail.

Montgomery (1995) published preliminary results of a study aimed at identifying how multimedia in particular can be used to address the needs of various learning styles. Results indicate that active learners appreciate the use of movies and interaction while sensors benefit from the demonstrations.

Although a glimmer of interest in CLT exists, there is a distinct lack of a clear and organized framework to help guide educational interface designers.

ALIGNMENT MAP FOR MULTIMEDIA INSTRUCTIONAL INTERFACE

The problems that arose with learning styles reveal a need for a more fine-grained isolation of various cognitive areas that may influence learning. Consequently, an alignment map as shown in table 1 may offer some guidelines as to what aspects of the multimedia interface design would benefit from what branch of the theory in order to gain a clearer channel of communication between the designer and the student.

Multimedia design issues	Cognitive areas that may be of relevance
1. Amount of media offered.	1. Cognitive load. 2. Limited attention span. 3. Interference between different mental representations.
2. How the Screen is partitioned.	1. Perception and recognition. 2. Attention
3. Parallel delivery of information.	1. Redundancy could cause interference. 2. Limited working memory (Cognitive load issues). 3. Limited attention span. 4. Learner difference.
4. Use of Colors.	1. Affects attention focus. 2. Perception of edges to promote recall.
5. Use of Animation.	1. Cognitive Load reduction. 2. Accommodates visualizer/verbalizer learners.
6. Use of Interactivity.	1. Cognitive load reduction. 2. Raises the level of learning objectives.
7. Aural media.	1. Speech perception issues like accent and

	clarity. 2. Interference with other media.
8. Verbal presentation of material.	1. Clarity of communication 2. Accommodates verbal/serialist learners.

Table 1: Alignment map from multi-media design questions to various cognitive research areas that may be of relevance.

CASE STUDY: DATA STRUCTURES MULTIMEDIA TUTORING SYSTEM

The alignment map presents itself as an excellent basis against which basic design issues of multimedia systems may be considered with the goal of making the best possible decisions.

The multimedia tutoring system considered here (Albalooshi & Alkhalifa, 2002) teaches data structures and was designed by considering the various design issues as dictated by the alignment map that was specifically designed for the project and is shown in table 1. An analysis of the key points is given below:

1. *Amount of media offered*: The system presents information through textual and animated presentation only. This is done to avoid cognitive overload caused by redundancy (Jonassen, 1991) that would cause students to find the material more difficult to comprehend.
2. *How the Screen is partitioned*: The screen grants two thirds of the width to the animation window which is to the left of the screen while the verbal description is to the right. Although the language used for the textual description is English, all students are Arabs so they are accustomed to find the text on the right side of the screen because in Arabic one starts to write from the right hand side. This design, therefore, targeted this particular pool of students to ensure that both parts of the screen are awarded sufficient attention. It presents an interface that requires divided attention to two screens that complement each other, a factor which according to Hampson (1989), minimizes interference between the two modes of presentation.
3. *Parallel delivery of information*: Redundancy is desired when it exists in two different media because one re-enforces the other. It is not desired when it exists within the media as when there is textual redundancy and things are explained more than once. Consequently, the textual description describes what is presented in the animation part especially since only text and animation media exist in this case, which means that cognitive load issues are not of immediate concern (Jonassen, 1991).
4. *Use of Colors*: Colors were used to highlight the edges of the shapes and not on a wide scale to ensure that attention is drawn to those. By doing so, focus is expected to be directed towards the object's axes as suggested by Marr and Nishihara (1978) in order to encourage memory recall of the shapes at a later point in time.

5. *Use of Animation*: The animated data structures are under the user's control with respect to starting, stopping, or speed of movement. This allows the user to select whether to focus on the animation, text or both in parallel without causing cognitive overload.
6. *Use of Interactivity*: The level of interactivity is limited to the basic controls of the animation.
7. *Aural media*: This type of media is not offered by the system.
8. *Verbal presentation of material*: The verbal presentation of the materials is concise and fully explains relevant concepts to a sufficient level of detail if considered in isolation of the animation.

EVALUATION OF THE SYSTEM

The tool was first evaluated for its educational impact on students. It was tested on three groups: one exposed to the lecture alone; second to a regular classroom lecture in addition to the system; third to only the system. Students were distributed among the three groups such that each group had 15 students with a mean grade similar to the other two groups to ensure that any learning that occurs is a result of the influence of what they are exposed to. This also made it possible for 30 students to attend the same lecture session composed of the students of groups 1 and 2 while 30 students attended the same lab session composed of the students of group 2 and 3 to avoid any confounding factors.

Results showed a highly significant improvement in test results of the second group when their post-classroom levels were compared to their levels following use of the multimedia system with an overall improvement rate of 40% recorded with $F=9.19$ with $p < 0.005$ from results of an ANOVA test after ensuring all test requirements have been satisfied. The first and third groups showed no significant differences between them.

Results shown indicate that learning did occur to the group that attended the lecture and then used the system, which implies that animation does fortify learning by reducing the cognitive load. This is especially clear when one takes the overall mean grade of all groups which is around 10.5 and checks how many in each group are above that mean. Only 6 in group one were above it, while 11 were above it in group 2 and 10 in group 3. Since group 3 was exposed the system only option, and achieved a number very close to group 2 that had the lecture and the system option, then clearly multimedia did positively affect their learning rate.

Since one of the goals of the system is to accommodate learner differences, a test was run on group 2 students to identify the visualizers from the verbalizers. The paper-folding test designed by French *et al* (1963) was used to distinguish between the two groups. The test requires each subject to visualize the array of holes that result from a simple process. A paper is folded a certain number of folds, a hole is made through the folds then the paper is unfolded. Students are asked to select the image of the unfolded paper that shows the resulting arrangement and results are evaluated along a median split as high versus low visualization abilities.

These results were then compared with respect to the percentage of improvement as shown in table 2. Notice that the question numbers in the pre-test are mapped to different questions numbers in the post-test to minimize the possibility of students being able to recall them; a two-part question was also broken up for the same reason.

	Q1 plus Q8 mapped to Q1	Q3 mapped to Q2	Q4 mapped to Q3	Q6 mapped to Q6
Visualizer Group	27.8%	18.6%	9.72%	9.76%
T-Test results	.004	.003	.09	.01
Verbalizer Group	20.7%	22.8%	21.4%	15.7%
T-Test results	.004	.005	.003	.009

Table 2: The percentage improvement of each group from the pretest to the post test across the different question types.

Results indicate that although the group was indeed composed of students with different learning preferences, they all achieved comparable overall improvements in learning. Notice though the difference in percentage improvement in Question 4. The question is: List and explain the data variables that are associated with the stack and needed to operate on it. This particular question is clearly closer to heart to the verbalizer Group than to the visualizer group. Therefore it should not be surprising that they find it much easier for them to learn how to describe the data variables than it is for students who like to see the stack in operation. Another point to consider is that the visualizer group made a bigger improvement in the Q1+Q8 group, in response to the question: Using an example, explain the stack concept and its possible use. Clearly, this question is better suited to a visualizer than to a verbalizer.

FUTURE TRENDS

CLT has already presented us with ample evidence of its ability to support the design of more informed and therefore more effective educational systems. This article offers a map that can guide the design process of a multimedia educational system by highlighting the areas of CLT that may influence design. The aim, therefore, is to attract attention to the vast pool of knowledge that exists in CLT that could benefit multimedia interface design.

CONCLUSION

This article offers a precise definition of what is implied by a computer-based cognitive tool (CT) as opposed to others that were restricted to a brief definition of the concept. Here, the main features of multimedia were mapped onto cognitive areas that may have influence on learning and the results of an educational system that conforms to these design requirements were exhibited.

These results are informative to cognitive scientists because they show that the practical version must deliver what the theoretical version promises. At the same time, results are informative to educational multimedia designers by exhibiting that there is a replicated theoretical groundwork that awaits their contributions to bring them to the world of reality.

The main conclusion is that this is a perspective that allows designers to regard their task from the perspective of the Cognitive Systems they wish to learn so it shifts the focus from a purely teacher-centered approach to a learner-centered approach without following the route to constructivist learning approaches.

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Terms and Definitions

Alignment Map: A representation on a surface to clearly show the arrangement or positioning of relative items on a straight line or a group of parallel lines.

Attention: It is an internal cognitive process by which one actively selects which part of the environmental information that surrounds them and focuses onto that part or maintains interest while ignoring distractions.

Cognitive Learning Theory: The branch of Cognitive Science that is concerned with cognition and includes parts of cognitive psychology, linguistics, computer science cognitive neuroscience and philosophy of mind.

Cognitive Load: The degree of cognitive processes required to accomplish a specific task.

Interface Design: The design of the point of communication between a human a computer that is utilized with a system.

Learner Differences: This describes the differences that exist in the manner in which an individuals acquires information.

Multimedia System: Any computer delivered electronic system that presents information through different media that may include text, sound, video computer graphics and animation.