Chapter XX

Cognitive Perspective on Human-Computer Interface Design

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ABSTRACT

This chapter focuses on the design of human-computer interface, particularly the software interface design, by examining the relationship between the functionality and features of the interface and the cognitive factors associated with the design of such interface. A design framework is proposed followed by an empirical study to validate some of the theoretical assumptions of the framework. The findings indicate that learners become more perceptually engaged when a multiple sensory-input interface is used. Our study also shows that building affective interaction at the perceptual level could significantly enhance learners' perceptual engagement which further leads them to cognitive engagement. Guidelines for designing an effective interface are proposed. The significance of the study is discussed with some suggestions for future study.

INTRODUCTION

The advancement of new digital technologies has brought a spectrum of changes in our society, particularly in the areas of education, industry, commerce, government, and so forth. According to a recent study, use of computers and Internet access at school rose from 51% in 1998 to 93% in 2003 (National Center for Education Statistics, 2005). The U.S. Department of Labor 2002-2012 employment projections indicate that 8 of the 10 fastest growing occupations require technological fluency (Bureau of Labor Statistics, 2007). Coupled with this increasing computer technology use is the issue of human-computer interface (HCI) design. Wallace and Sinclair (1995) express their concern about the negative cognitions and attitudes towards technology caused by poorly designed human-computer interface related to both hardware and software. Preece, Rogers, and Sharp (2002) argue that the hardware may work effectively from an engineering perspective but can cause "numerous people immense grief" at the expense of "how system will be used by real people" (p. 1). They called for a systematic study of the human-computer interface that focuses on both hardware and software by examining the human factors pertaining to human-computer interaction.

While the hardware issue is worth attention with regard to the physical interactivity between the user and the computer as well as the impact of such interactivity on the user's information process (Kroemer & Kroemer, 2001; Patterson & Hennessy, 2005), studies on software design and user relations begin to emerge. Numerous studies have been conducted in screening behavior and human cognition (Kearny & Smith, 1999), mental model and computer implementation (Goodwin & Johnson-Laird, 2005), computer-related tasks and human factors (Serenko, 2006), agent-based human-computer interaction (Baylor, 2002, 2004; Moreno & Mayer, 2004), and so forth. There has been a considerable interest in understanding the relationship between human cognition and software interface design. Scholars from computer science and cognitive psychology (Mayer & Moreno, 2003; Norman, 1988; Schneiderman, 1980, 1982) concurred that an appropriately designed software interface can facilitate learners' cognitive information process. For example, Schneiderman's theory of direct manipulation and Mayer and Moreno's principles of multimedia learning design have shown that the learner's ability to process information can be affected by the mode of interactivity where human cognition is intertwined with the design of the computer interface.

So far, most research has mainly focused on the general relationship between human cognition and computer interface, few studies have been done to explore the underlying operational conditions that facilitate the cognitive information process through the computer interface which has been the key subject in the study of software ergonomics. This chapter describes the characteristics of human perceptions, and how such characteristics affect human information process both in short-term memory and long-term memory. Emphases will be made on the idiosyncratic features of the computer interface and the cognitive attributes associated with such features in human information processing.

The purposes of this chapter are:

1. Defining the software interface design by identifying its underlying concepts;
2. Discussing the issues related to software interface design;
3. Presenting related cognitive theories pertinent to effective interface design; and
4. Proposing guidelines for effective software interface design.

COGNITIVE FUNCTIONS AND SOFTWARE INTERFACE DESIGN

Oftentimes, software designers become confused about what users' needs are. Part of this is caused by a lack of understanding of the cognitive functions related to the interface. Sugar (2001) conducted a study on novices who designed hypermedia. He found that the novices had difficulty in fixing the flaws identified by the users based on a usability test. Most novice designers used Band-Aid solutions that merely answered direct, obvious problems but hardly addressed and repaired complex, indirect problems. Sugar's study addressed an important issue that has significant ramifications in human-computer interface design: What is the skill set and knowledge base that are essential for designing an effective software interface?

For many people, the interface design is about the graphics, programming, and the layout of the interface elements. For others, it means to incorporate the patterns of human behavior and cognitive functions into the design of software. A case in point is to design the interface of a calculator that matches the cognitive architectures within the program. Kozma (1994) argues that the cognitive attributes of software can expand a learner's capacity in cognitive learning. For example, the rotational function of an animated 3D program in math and science can help learners understand the abstract concepts, thus improve their learning. Understanding the cognitive functions and how they relate to a cognitive information process is important for effective interface design. Thus, knowledge about the graphics, programming, as well as cognitive functions related to the interface is essential for software designers who want to create usable interfaces that meet the needs of users.

Research shows that cognitive functions such as perception and the ability to formulate external and internal representations are related to interface design (Ziegler, Vossen, & Hoppe, 1990). Human perceptions and cognitive engagement can be affected by the way the interface is designed. For instance, the interface that is text only, or text with images, or images, only can affect the learner's information process differently depending on the cognitive and learning styles of the learner. Therefore, it is critical to examine the cognitive functions (e.g., perceptions, mental representations) in interface design. Likewise, it is important to understand the role of interface components (e.g., modality, locus of control) and how they can be optimally designed to promote cognitive functions in learning.

HUMAN PERCEPTIONS AND INTERFACE

Software interface design refers to the design of software applications with a focus on the user's experience and interaction. It involves both the external and internal representations of learning objects. The external representation includes the interface layout of a software application, the multimodal information delivery, and so forth. The internal representation refers to the cognitive architectures that simulate human cognitive process in learning. Schneiderman (1980) defines the study of software interface design as something that "applies the techniques of experimental psychology and the concepts of cognitive psychology to the problems of computer and information science" (p. 3).

It is believed that human-computer interaction is largely influenced by the user's perceptual abilities which include the range of visibility, perceptual focus, attention, and so forth. These abilities are further affected by the design elements embedded in the interface, that is, color, text size, text/graphic ratio, and others (Blake & Sekuler, 2006). Blake and Sekuler point out that perception is a biological process that "provides us with a useful view of the world, where useful means being able to interact safely and effectively within our environment" (p. 1). In a human-computer environment, this means focusing on the important information and ignoring the irrelevant. What is it that influences the choice of perception? According to Blake and Sekuler, four interfaces have critically influenced the choice of perception. They include (a) constructive, (b) contextual, (c) interpretative, and (d) synchronizing interfaces (Figure 1).

Constructive Interface

From an interface design perspective, the user's ability to construct meaning is determined by the visual elements that create "the constructive nature of visual perception" (Blake & Sekuler, 2006, p. 111). In other words, the visual interface should allow the brain to go beyond the optical information provided by the eye and generate plausible interpretations. Panel A of Figure 1 underscores the constructive nature of visual perception by providing an illusory figure (e.g., triangle) that the user is be able to construct. Studies show that constructing or making meaning via visual elements in the interface can enhance users' engagement with the software (Hyerle, 1996).

Contextual Interface

One of the key principles in software interface design is to provide meaningful context for users to engage in meaningful interaction (Preece et al., 2002). Blake and Sekuler (2006) state that the brain does not concentrate on individual features in isolation but, instead, exploits relationships among features as contextual clues about how those features ought to be knitted together. In panel B of Figure 1, the faces of the hexagon cone at the top of the panel have been embedded in the whole hexagon cone below. The user does not fully understand the use of the segment of the hexagon faces until they become part of the entire hexagon figure. Blake and Sekuler thus argue that meaningful perception occurs when the part is perceived as relevant to a whole object.

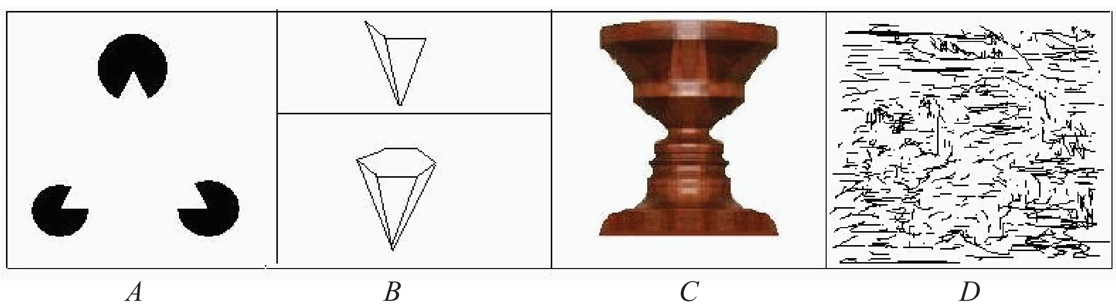
Interpretative Interface

The notion of interpretative interface originates from the concept of the relativity of human perception. Human perception can fluctuate between alternatives when an ambiguous interface is presented. For example, Panel C of Figure 1 entails multiple interpretations that the user probably has trouble deciding what the user sees. At one moment the figure appears to be a chess trophy against a white background but then, without warning, it turns into a pair of white faces looking at each other against a mahogany background. Researchers caution that interpretative interface can lead to confusion and misinterpretation of the purpose of the interface. It is suggested that the interface design should minimize ambiguity and reduce the chance of multiple interpretations from the user.

Synthetic Interface

The synthetic interface refers to the user's ability to piece bits of information together to form a perception of what is initially considered indecipherable. Panel D of Figure 1 looks like a collection of black splotches. To make sense of this picture, your visual system must synthesize contour and texture information gathered from a large portion of the picture, and try to figure out which pieces of the image go together. The human ability to visually synthesize clues from a seemingly random collection of splotches proves that visual perception depends on more than just the pattern of light striking the retina. Perception, rather than being a mindless process of measuring how much light enters the eye, is an intelligent activity of a finely tuned brain. Understanding human ability to visually synthesize information enables the designer to design an engaging software interface that facilitates higher level thinking such as pattern recognition and information synthesis.

Figure 1. Meaningful perceptual determinants for constructive, contextual, interpretative and synthetic interfaces



BEYOND THE INTERFACE: MENTAL REPRESENTATIONS

As part of the human cognitive process, perception provides critical information for cognitive information processing. However, information derived from perceptions can sometimes be insufficient in terms of deep mental operation. For example, text-based input can cause problems for visual users to form a mental representation of the external object because such users often rely on visual forms to help externalize the abstract concepts in the text. Thus, the effects of interface can be mitigated if the user's ability to create a mental representation of the external object is compromised due to the limitation to a particular type of perceptual interface. In other words, the user may not be able to process information effectively if there is a discrepancy between user's cognitive style and the interface presented. In the last two decades there has been an increasing interest in designing cognitively functional interface (Schneiderman, 2005). Two theories have played contributing roles toward designing cognitively functional human-computer interface. They are (a) dual coding theory and (b) cognitive load theory.

Dual Coding Theory

Paivio (1986) suggested that the input information is processed through multiple sensory channels. For example, the verbal information is registered through the verbal channel whereas the nonverbal information such as images is registered through the nonverbal channel. According to dual coding theory, there are three levels of processing pertaining to incoming verbal and nonverbal information: representational, associative, and referential. The representational process refers to the connections between the external object and internal representation of the object. The associative process means the activation of the information stored within the long-term memory. Depending on the input stimuli, the activation process can be either in the verbal or nonverbal (e.g., visual) system. The referential process is the cross-reference process between the verbal and nonverbal systems. Research on dual coding practices suggests that pictures can be coded both visually and verbally, whereas words are believed to be far less likely to be coded visually (Paivio, 1991; Rieber, 1994).

Mayer and Sims (1994) examined the effects of text (monosensory mode) vs. multimedia (multiple sensory mode) on learners' ability to solve problems. They found that instructions with multimedia facilitate learners' comprehension and knowledge transfer. They concluded that multiple sensory inputs such as multimedia enable learners to construct meaning more effectively than does the monosensory input.

Cognitive Load Theory

Although dual coding theory describes the cognitive process in terms of information encoding, it fails to address a very important issue in information process, that is, the human capacity to handle incoming information. In other words, how much incoming information should be delivered at the moment of learning? What is the optimal way to deliver the information so that the learner can efficiently encode the incoming information?

Studies show that working memory is very limited in both duration and capacity. Van Merrienboer and Sweller (2005) observe that working memory stores about seven elements but normally operates on only two or three elements. They also find that working memory can deal with information "for no more than a few seconds with almost all information lost after about 20 seconds unless it is refreshed by rehearsal" (p. 148). When working memory becomes overloaded with information, learning can be adversely affected (Paas, Tuovinen, Tabbers, & Gerven, 2003; Sweller & Chandler, 1994; Marcus, Cooper, & Sweller, 1996). According to the cognitive load theory (CLT), three types of cognitive load exist: *intrinsic load*, *extraneous* or *ineffective load*, and *germane* or *effective load*.

The intrinsic cognitive load refers to a cognitive load that is induced by the structure and complexity of the instructional material. Usually, teachers or instructional designers can do little to influence the intrinsic cognitive load. The extraneous cognitive load is referred to the cognitive load caused by the format and manner in which information is presented. For example, teachers may unwittingly increase a learner's extraneous cognitive load by presenting materials that "require students to mentally integrate mutually referring, disparate sources of information" (Sweller & Chandler, 1991, p.353). Finally, the germane cognitive load refers to a cognitive load that is induced by learners' efforts to process and comprehend the material. The goal of CLT is to increase this type of cognitive load so that the learner can have more cognitive resources available to solve problems (Brunken, Plass, & Leutner, 2003; Marcus et al., 1996).

Relationship between Intrinsic and Extraneous Load

The difficulty of a subject area is determined by both the number of elements that must be learned and the extent to which they interact. According to Sweller and Chandler (1994), the cognitive load imposed by the intrinsic nature of the material is determined solely by element interactivity, not by the total number of elements that must be assimilated. For instance, in science learning the learner not only must learn the concepts but also must understand the relationship between the concepts. The cognitive load associated with learning the concepts is low because the elements of the materials to be learned do not interact with each other whereas the cognitive load involved in learning the relationship between the concepts can be high because the learning not only taxes our limited processing ability but also our ability to assimilate large amounts of information into long-term memory over relatively short periods (Lee, Plass, & Homer, 2006). Sweller and Chandler (1994) point out that materials with a high degree of interactivity that would impose high intrinsic cognitive load are particularly susceptible to any extraneous cognitive load imposed by the manner of presentation. The extraneous cognitive load is imposed purely because of the design and organization of the learning materials rather than the intrinsic nature of the task. However, if the intrinsic element interactivity and consequent cognitive load is low, the extraneous cognitive load caused by instructional design may not be very important. In contrast, extraneous cognitive load is critical when dealing with intrinsically high element interactivity materials (Sweller & Chandler, 1991, 1994).

The cognitive load theory has been widely adopted in the design of instruction, particularly in the learner-interface design. Efforts have been made to facilitate the user's mental representation in learning by designing interfaces that would reduce the cognitive load. Opfermann, Gerjets, and Scheiter (2007) studied the media effects and cognitive load in a hypermedia environment and found that the hypermedia interactive interface provides better learner control and is conducive to prior knowledge activation, which would help reduce both intrinsic and extraneous cognitive load in learning. Opfermann et al.'s findings concurred with the study by Lee et al. (2006) who found the use of optimized visual displays promoted comprehension and transfer, especially for low prior-knowledge learners.

DESIGNING COGNITIVELY FUNCTIONAL INTERFACE

As it was discussed above, the problems with the design of perceptual interfaces is that the input information from the perceptual interfaces does not necessarily facilitate information processing at a deeper level. For example, a contextual interface with monosensory input may hinder the user's information process as the information process in contextual interface depends on multiple perspectives and clues. Likewise, the user may have difficulty constructing an external representation in mind when the information presented in Panel A of Figure 1 is delivered text only. The distributed cognition theory (Hitchins, 1995) posits that cognitive process is a sharing and interacting process that includes both external and internal representations. When the external representation is conveyed through perceptions, the executive control systems in the brain respond by activating prior knowledge, connecting it with the input information to form an internal representation of the external representation. Comprehension occurs when there is a meaningful connection between the external and internal representations. Conversely, the user's ability to comprehend can be affected if the connection between external and internal representations deteriorates due to, for example, a cognitive overload. There are several issues related to interface design that have affected the use and application of software.

Issues in Software Interface Design

A major challenge for interface designers is to design and develop applications that engage users in various tasks efficiently. A review of the relevant literature revealed that interface control, cognitive overload, poor interactivity, and lack of flexibility are among the key issues that continue to affect the design of effective interface (Dix, Roselli, & Sutinen, 2006; Laurel, Oren, & Don, 1990; Teege, Kahler, & Stiemerling, 1999).

System Control vs. Learner Control

There has been a considerable debate on whether the interface should be system-controlled or learner-controlled (Kay, 2001; Laurel et al., 1990; Sedig, Klawe, & Westrom, 2001; Teege et al., 1999). Teege et al. concluded that the system control approach, that is, the learner followed a sequence of steps defined by the system, can limit users' creative and innovative thinking. Kay (2001) cautions that the system control approach could result in low interactivity and lack of flexibility in interface design. He argues that the design of software interface should "give the learner greater responsibility and control over all aspects of the learning" (p. 111). Sedig et al. (2001) suggest that a balanced approach should be taken. They pointed out that learner control and system control were inextricably coupled. While allowing some degree of learner control, an instructional source must be capable of certain system control, including taking learner input, assessing learner performances, providing appropriate feedback, adapting to changing needs, and advancing the learner in the right direction.

The above issue can be best understood in light of recent development in *agent-based* learning environments (Baylor, 2002, 2004; Moreno & Mayer, 2004). Agent-based design consists of dynamically interacting rule-based agents. The systems within which they interact can therefore create complexity like that which we see in the real world. Moreno and Mayer conducted a research on teaching science through an agent-based multimedia game. The subjects were self-initiated to design the roots, stem, and leaves of plants to survive in five different virtual environments. While they were given full learner control in terms of selecting a natural environment and designing trees to survive in the natural environment, the subjects were guided by a built-in control system called agent who gave advice on a range of topics from soil selection to the DNA structure of trees. Thus, Moreno and Mayer's research proposed a system control of knowledge acquisition while giving full learner control to the use of the knowledge after it has been acquired. Parallel with this effort is Baylor's (2002, 2004) multiple intelligent mentors instructing collaboratively (MIMIC) system which uses agent-based computer environments to help preservice teachers apply educational theories to their design of instruction. The agent in MIMIC system represents a particular educational theorist, such as Piaget. Preservice teachers can select one or several agents for their lessons. The agent will provide feedback based on the lesson presented and advise the preservice if his/her lesson fits well with the theory as represented by the agent. The system significantly enhanced preservice teachers' understanding of the educational theories as well as their ability to apply those theories to their teaching and learning. The MIMIC system takes an eclectic approach by allowing both learner and system controls in learning the educational theories.

The balance between system control and learner control is important in the human-computer interface design (Baylor, 2002, 2004; Sedig et al., 2001). Baylor (2004) identifies four dimensions of learner/system control in the design of agent-based computer environment: the first dimension of control involves instantiating the "instructional purpose" of the environment on a constructivist (high learner control) to instructivist (high program/*agent* control) continuum; the second dimension entails managing "feedback," involving issues of type, timing, amount, explicitness, and potential for learner choice; the third dimension involves the desired "relationship" of the learner to *agent*(s) (e.g., *agent* as learning companion, *agent* as mentor, multiple pedagogical *agents,* or *agent* as personal assistant); and the fourth dimension defines the degree of agent control in which the learner would develop "confidence" in the *agent*(s) in terms of believability, competence, and trust. Perceivably, the four dimension framework proposed by Baylor reflects a balanced approach toward human-computer design with regard to system and learner control. As the agent-based design has become increasingly prominent in computer assisted instruction (CAI), the framework provides instructional and software designers with a practical guidance that can be used to identify and drive decision-making processes that occur during the design and development of instruction.

Cognitive Overload

The issue of cognitive overload has been of much concern to both researchers and designers. Laurel et al. (1990) found that inappropriately designed interface can cause cognitive overload which would further affect the learner's comprehension, understanding, and the ability to learn or solve problems. Davis and Bostrom (1993) points out that the cognitive overload issue may be related to the interface design, such as presentation modes (i.e., monosensory vs. multiple sensory modes), the application retrieval system (i.e., recall vs. recognition), and so forth.

Factors Related to Effective Human-Computer Interface

Research has shown that factors such as direct manipulation, flexibility, cognitive architectures, and so forth are important in creating effective human-computer interface (Byrne, 2003; Schneiderman, 2005; Stiemerling, Kahler, & Wulf, 1997). In this chapter we focus on direct manipulation, flexibility, and cognitive architectures which we believe are particularly relevant to the cognitive aspects of interface design.

Direct Manipulation

Schneiderman (1982) suggests that the interface design should allow the user to directly manipulate objects presented to them, using actions that correspond at least loosely to the physical world. Schneiderman's theory of direct manipulation emphasizes manipulation through sensory perceptions including visual, auditory, haptic, and others. Direct manipulation employs real-world metaphors for objects and actions which make it easier for a user to learn and use an interface. Additionally, rapid, incremental feedback allows a user to make fewer errors and complete tasks in less time, because they can see the results of an action before completing the action (Iwata, 2003; Preece at al., 2002). Direct manipulation recognizes the role of both external and internal representations in the cognitive process. It facilitates information process through multiple sensory channels, the notion of which has been supported by several cognitive theories discussed above.

Flexibility

Flexibility in software interface design entails a broad conceptual framework that "concerns not the regular procedures and standard way of doing things but the unexpected, unprecedented, the exceptional cases, situations and events" (Stiemerling et al., 1997, p. 367). According to Stiemerling et al (1997), flexibility means (a) aligning a human cognitive profile with the cognitive architecture and (b) meeting dynamically evolving and differentiated requirements. Designing an interface that aligns a human cognitive profile with the cognitive architecture means the designer needs to take into consideration how users' cognitive and learning styles (e.g., auditory, visual, logical, etc.) can be matched with the cognitive architectures (i.e., the logical algorithm of cognitive thinking) in the software. For example, the interface design of a calculator requires a thorough understanding of the cognitive architecture within the program of the calculator, that is, the steps that simulate how humans calculate numbers, as well as an elaborative thinking on how the interface would support users with different cognitive and learning styles. That is, all users, visual or auditory, would be able to perform the calculation with the same efficiency.

Building flexibility into interface design also means to dynamically meet various requirements of the user. It requires the interface to be designed in a way that the user can, for example, select and combine multiple fields, control the level of difficulty, transfer files through multiple platforms, and so forth. Stiemerling et al (1997) note that allowing users to select levels of difficulty in tasks or providing the option of combining multiple fields in information search, for example, can enhance users' ability to engage in complex learning and promote skills in both well-structured and ill-structured problem solving.

Cognitive Architectures

The concept of cognitive architecture originates from cognitive science related to the early days of cognitive psychology and artificial intelligence, as manifested in the general problem solver (Newell & Simon, 1963), one of the first successful computational cognitive models. However, cognitive architectures differ from traditional research in psychology in that work on cognitive architecture is integrative. That is, they include attention, memory, problem solving, decision making, learning, and so on (Byrne, 2003). The notion of cognitive architecture has been widely used in the gaming, intelligent tutorials, and the like. Cognitive architectures have been identified and integrated in the design of programming. For instance, in designing a math problem solving tutorial, the cognitive algorithm related to math problem solving should be identified, followed by an analysis of the sequence of behaviors to successfully carry out the math problem solving. The computational model of math problem solving thus reflects the structure of human cognition and a specific domain of knowledge. The cognitive architectures can be integrated in programs that help users perform simple calculations, make quantitative predictions, and so on. Designing interfaces that optimize human performance with the cognitive architecture in the program is one of the endeavors pursued by aspiring interface designers.

A FRAMEWORK FOR SOFTWARE INTERFACE DESIGN

In this section of the chapter we would like to propose a framework for effective interface design. Having identified various factors related to interface and information processing, we would go further to explore the commonality among the variability in terms of interface design. Our approach would be to use Wang and Gearhart's (2006) research as a basis to develop our framework of effective interface design.

The concept of interaction has been much studied in the areas of general learning, counseling, and other fields including interface design. Wang and Gearhart (2006) identify three dimensions of interaction, namely, cognitive, affective, and social interactions.

Cognitive Interaction

The cognitive interaction means cognitive engagement through interactive approaches such as providing informative feedback to learners. Wang and Gearhart (2006) assert that informative feedback can help reveal gaps or inconsistencies in users' existing knowledge and prompt them to refine their understanding and acquire new knowledge.

Affective Interaction

The affective interaction means the user becomes motivated and engaged in what the user is doing. Research shows that motivation is influenced by several factors including the aesthetic appeal, relevance, usability, and self-efficacy related to learning and performance (Naquin & Holton, 2002; Teo, Lim, & Lai, 1999). The difference between cognitive interaction and affective interaction is that the former shows a cognitive engagement whereas the latter displays an emotional attachment.

Social Interaction

Social interaction is a continuous interaction between the user and what surrounds the user. Research shows that meaningful learning occurs where a socially organized environment is supported (Salomon, 1981; Vygotsky, 1978). Social interaction promotes both cognitive and affective development.

According to Wang and Gearhart (2006), two levels of information processes exist; they are perceptual and conceptual information processes. The perceptual information process refers to the initial interaction with the interface where the information is processed through sensory channel(s) whereas the conceptual information process refers to cognitive engagement with the content after the initial perceptual information is completed.

Wang and Gearhart's work provides a common ground for lining up various factors identified in the previous section. For example, many operational concepts related to interface design such as direct manipulation, flexibility, and cognitive architectures can be subsumed under the construct of cognitive interaction. Additionally, the cognitive factors such as cognitive load discussed above can be related to cognitive interaction as well as social interaction as we examine social and behavioral patterns in a human-computer interface environment. In short, Wang and Gearhart's categorization of human interaction and levels of information processes is relevant to the interface design. Based on their work, we propose a framework for effective interface design by crisscrossing the levels of information processes (i.e., perceptual and conceptual) with the types of access (i.e., interface and content) in terms of the interactions described in Wang and Gearhart's study. Figure 2 shows a matrix that illustrates the relationship between perceptual-conceptual and interface-content in design.

The above perceptual-conceptual and interface-content matrix presents a framework that identifies the relationship between information process and access as users engage in various interactions with the interface. A detailed description of the relationships follows.

Perceptual-Interface Relationship

The perceptual-interface relationship emphasizes a sensory information process and its relations with the interface. The perceptual-interface relationship occurs when the user first accesses the interface through sensory channels. The user's perceptions could be influenced by the aesthetic appeals of the interface and the mode presented (i.e., mono vs. multimodal interface). The affective and, in some cases, social interactions are the primary forms of interaction for the perceptual-interface relationship.

Perceptual-Content Relationship

As the initial sensory information is processed through the working memory, the user becomes cognitively engaged, trying to make sense of the new information by connecting it with prior knowledge. However, the information received through the sensory channels can become less useful if the user becomes cognitively overloaded by the input information due to an inappropriate delivery of information, such as presenting through a mono-sensory channel. Other issues such as lack of flexibility and feedback can hamper users' information process as well. The primary mode of interaction in the perceptual-content relationship is cognitive interaction between the user and the content. However, affective and perhaps social interactions are still possible and may continue to influence the user at this stage.

Conceptual-Content Relationship

The conceptual-content relationship reflects users' cognitive engagement with the content. Such engagement is marked by a high adaptation of the interface to users' learning and cognitive style. The cognitive interaction is the predominant mode of interaction with social interaction being used in some situation. The affective interaction is possible but less essential at this stage.

It should be noted that there is no conceptual-interface relationship because cognitive engagement occurs after the initial perception. The cognitive activity of conceptualization takes place where there is the content. Initial perceptions at the interface level are essentially guided by the impression that is based more on aesthetic appeals or values than cognitive conceptualization.

The above framework identified the relationship between information process and access in terms of cognitive, affective, and social interactions. It is a descriptive approach that emphasizes the components rather than the algorithm of interface design. The following study is an example of applying the framework to design an effective interface.

Figure 2. The perceptual-conceptual and interface-content matrix

Levels of info. processes Types of access	Perceptual	Conceptual
Interface	Interaction: • Affective Interaction • Social Interaction Design • Aesthetic appeals • Mode	
Content	Interaction: • Cognitive interaction • Affective Interaction • Social Interaction Design • Mode • Flexibility • Feedback	Interaction: • Cognitive Interaction • Social Interaction • Affective Interaction Design • Adapting to users' learning and cognitive styles

A STUDY: EFFECTS OF INTERFACES ON LEARNERS' PROBLEM-SOLVING ABILITIES, COGNITIVE LOAD, AND SELF-EFFICACY

The purpose of the study was to investigate whether using different interfaces would affect learners' ability to solve problems, their cognitive load, self-efficacy, and spatial ability in problem solving. The perceptual-conceptual and interface-content framework was used to identify the levels of information processes and the types of access.

Interface Design

The focus of the interface design was to help learners efficiently solve a particular type of problems: the multiple rule-based problem which is characterized by a high intrinsic cognitive load. A detailed discussion of the multiple rule-based problems is presented in the next section. According to Sweller and Chandler (1991, 1994), extraneous cognitive load is critical when dealing with intrinsically high element interactivity materials. Using Mayer's (2001) principle of contiguity in multimedia design, we made the problems and questions along with the pictures in the same screen to reduce extraneous cognitive load in learning. That is, learners did not have to mentally assimilate information from different places (i.e., separate computer screens) to solve problems. To test whether using different instructional mode would engage learners' cognitive engagement differently, two versions of interfaces were created: interactive multimedia and noninteractive multimedia with the assumption that the interactive multimedia interface would be more effective than the noninteractive multimedia interface in terms of cognitive load reduction, self-efficacy, and problem-solving skills.

The Study

The study was conducted during the fall of 2005 and the spring of 2006. Two hundred and twenty-two participants were recruited from three universities that included a large urban university and a private university in the northeastern region of the United States, and a midsize teaching university in the south. Of 222 participants, 32% ($n = 72$) were males and 68% ($n = 150$) were females. Approximately 87% ($n = 194$) were Caucasian and 13% ($n = 28$) were nonwhite. Participants varied in age from 19 to 57 years old, with a mean of 24 ($SD = 7.33$).

Instrumentation

Four instruments were used to measure (a) students' self-efficacy, (b) problem solving skills, (c) spatial ability, and (d) cognitive load involved in the problem solving. They include self-and task perception questionnaire (STPQ) scales, multimedia problem-solving tasks (MPSTs), and cognitive load questionnaire (CLQ).

Self-and task perception questionnaire (STPQ) scales. The STPQ scales was originally developed by Lodewyk et al. (2005) who reported internal consistency reliability coefficients before and after each task ranged from .72 to .92. The instrument was adapted for the study with the permission of the original authors. Changes were made to better fit the purpose of this study. For example, the statement "Knowing the difficulty of this project, the teacher, and my skills, I think I will do well on this project" was changed to "Knowing my skills and abilities, I think I will do well on problem solving." The instrument consisted of seven statements including: (a) Knowing my skills and abilities, I think I will do well on problem solving; (b) I expect to do well on problem solving; (c) I believe I will attain a high score on problem solving; (e) I'm confident I will gain the basic skills for problem solving; (f) I'm certain I have the skills necessary for problem solving; (g) I'm confident I will understand the most difficult problems; and

(h) I know which mental techniques would be the best for this problem solving. Participants reported answers on a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5). The total possible score one could obtain on the test was 35 points.

Multimedia problem-solving tasks (MPSTs). The problem solving tasks were developed by the first author using Flash MX, Adobe Photoshop, and Microsoft Active Server Page (ASP). The MPSTs were composed of six multiple-rule based problems that included: Air Traffic Control, Tower of Hanoi, Sailing Boat, Seating Arrangement, Taking Pictures, and Office Inspection. Each task consisted of two parts, that is, (a) a problem presented with text format along with a visual presentation (either interactive or noninteractive), and (b) multiple choice questions. The problem included a description of a problem situation and several mutually restricting conditions. The subject had to consider these conditions simultaneously before a solution could be reached. For example, Task 5, *Taking Pictures,* had a set of conditions that restricted the order of the individuals who could stand next to each other. The subject had to consider all the conditions and then decided the order in which individuals could take pictures without violating the conditions.

Two versions of a multimedia task interface were created: interactive and noninteractive. In the interactive multimedia interface, subjects were able to manipulate and move important components of the image (e.g., individuals). In the noninteractive multimedia interface, subjects were given a static visual representation of each problem. For each problem, subjects were asked to answer two questions that measured the subject's problem solving skills. After completing the two questions, the subject clicked the submit button. A timer recorded the start and the end of the response time for each set of two questions. The total possible score one could obtain on the test was 12 points.

Spatial orientation questionnaire (SOQ). The SOQ was developed by the first author. To meet the assumption of construct validity, the instrument was developed based on the theoretical constructs identified in the literature (e.g., Dermen, 1976; Gilford & Zimmerman, 1956; NewCombe & Huttenlocher, 2000). A three-item questionnaire was developed which consisted of (a) I have a good sense of direction, (b) I am a visual person, and (c) I am a hands-on person, with a Likert scale ranging from strongly disagree (1) to strongly agree (5). The questions were reviewed by a group of three panelists who were professors in educational psychology. The Cronbach's reliability test was conducted which reported an internal consistency reliability coefficients of .72. The total possible score one could obtain on the test was 15 points.

Cognitive load questionnaire (CLQ). The CLQ was a three item questionnaire developed by Homer, Plass, and Blake (2005). Changes were made to better fit the purpose of the study. The first item was the statement "In solving the preceding problems I invested" with a 9-point Likert scale ranging from *very low mental effort* (1) to *very high mental effort* (9). The second item included a statement of "I experienced the foregoing problem solving as" with a 9-point Likert scale ranging from *not difficult at all* (1) to *very difficult* (9). The third item was the question "How easy or difficult was the problem solving to understand?" with a 7-point Likert scale that ranged from *very easy* (1) to *very difficult* (7). The total possible score one could obtain on the test was 25 points.

Procedures

A randomization procedure was used to divide subjects into two groups: interactive and noninteractive multimedia interface applications. The subjects were given the URL to logon to the problem solving Web site. They were asked to complete a self-efficacy pretest, fill out a demographic information sheet, and then work on the MPSTs problem solving tasks. The subjects in the interactive multimedia group were able to move the figures to help solve problems whereas the subjects in the noninteractive multimedia group were provided with the same graphic except that they were not able to move the figures. None of the groups were allowed to use paper and pencil during their problem solving test. After finishing the MPSTs test, they were asked to fill out a cognitive load questionnaire and complete the self-efficacy posttest. It took about an hour and half for the subject to complete the entire experiment. Each participant was given a consent form to sign before each participant participated in the study.

Results and Analysis

The data analyses were performed with SPSS version 14. The correlation analysis and the independent samples *t*-test analyses were employed to analyze the relationship among the variables and determine whether the interface mode affected such variables as cognitive load, self-efficacy, spatial ability, and learners' performance in problem solving.

A correlation analysis was conducted by entering the variables of performance scores, cognitive load, spatial ability, and change in self-efficacy and interface mode. The results show that the interface modality was correlated significantly with the change in self-efficacy ($r = -.506, p < .01$), cognitive load ($r = -.581, p < .01$), and performance ($r = -.732, p < .01$). The change in self-efficacy was found to be significantly correlated with the cognitive load ($r = -.253, p < .01$) and performance ($r = .355, p < .01$). Finally, the cognitive load was significantly correlated with the performance ($r = -.466, p < .01$) (Table 1).

The independent samples *t*-test was performed to find out if there were differences between interactive and noninteractive interface modes with regard to learners' cognitive load, problem solving, and self-efficacy. Significant differences were found between the interactive interface mode and the noninteractive interface mode in learners' self-efficacy ($t(2, 220) = 8.701, p < .01$), cognitive load ($t(2, 220) = -10.585, p < .01$), and the performance ($t(2, 220) = 15.959, p < .01$) (Table 2).

Discussion

The results of the study indicated that the interface mode was significantly correlated with the change in self-efficacy, the cognitive load, and the performance in learning. Students who studied with the interactive multimedia interface mode had a higher self-efficacy, lower cognitive load, and better performance results than did their counterparts who learned with the noninteractive multimedia interface mode. The findings concurred with the literature that the multimodal interactive mode can reduce learners' cognitive load, thus improve their self-efficacy and performance in academic study (Mayer & Moreno, 2003; Zheng, Miller, Snelbecker, & Cohen, 2006).

The study supported the perceptual-conceptual and interface-content framework that learners' affective interaction played an important role for taking students further to cognitive interaction. The interactive multimedia interface, which has the advantage of engaging students in haptic learning and enabling them to process information through multiple sensory channels, provides the opportunity for effective student cognitive engagement by reducing learners' cognitive load, and consequently, enhances their self-efficacy in learning as well as academic performance.

GUIDELINES FOR EFFECTIVE SOFTWARE INTERFACE DESIGN

Learners' initial perception of the software interface is critical in that it can influence learners' further engagement with the software. The concept of initial perception has a broad connotation which refers to not only the aesthetical aspects of the design but also the functionality of application. For example, if an application has an appealing interface but requires considerable mental effort to process the

Table 1. Correlations among the variables

Correlations

		Change in				Interface
Change in self efficacy	Pearson Correlation	1	-.253**	.355**	-.069	-.506**
	Sig. (2-tailed)		.000	.000	.308	.000
	N	222	222	222	222	222
Cognitive load	Pearson Correlation	-.253**	1	-.466**	.053	.581**
	Sig. (2-tailed)	.000		.000	.436	.000
	N	222	222	222	222	222
Performance	Pearson Correlation	.355**	-.466**	1	-.024	-.732**
	Sig. (2-tailed)	.000	.000		.721	.000
	N	222	222	222	222	222
Spatialilty	Pearson Correlation	-.069	.053	-.024	1	-.042
	Sig. (2-tailed)	.308	.436	.721		.530
	N	222	222	222	222	222
Interface Modality	Pearson Correlation	-.506**	.581**	-.732**	-.042	1
	Sig. (2-tailed)	.000	.000	.000	.530	
	N	222	222	222	222	222

**. Correlation is significant at the 0.01 level (2-tailed).

information, then the chances are the learner will either become frustrated or turn away from the application to look for other alternatives.

As it was previously discussed, factors such as cognitive load, learner characteristics, locus of control, and so on can influence learners' information process and cognitive engagement. The perceptual-conceptual and interface-content framework was proposed here as an approach that can help improve and enhance the design of effective software interface. Although the framework cannot be expected to address all aspects of the issues in interface design, it can help designers to identify the critical elements in design by examining the cognitive, affective, and social interactions involved in human-computer interaction. Here are some general guidelines to consider:

1. The interface design should reach a balance between the beauty and the functionality of the software application. It should put in perspective such factors as the aesthetic appeal of the interface and the efficiency in information process.
2. The interface design at the perceptual level should facilitate the affective interaction in which the user feels connected and promoted to further cognitive engagement.
3. The interface design at conceptual level should allow flexibility with which the learner is able to control the levels of difficulty, range of the subject, and the mode of information process.
4. The interface design should facilitate, wherever possible, social interaction in which the cognitive process is distributed between learners and learners, and between learners and software application.
5. Following user interaction with interface design, designers should update and/or change any part of the interface that does not meet the above guidelines from user perspective.

CONCLUSION

This chapter focuses on the design of human-computer interface, particularly the software interface design, by identifying the factors that are critical to the design process. The factors can be subsumed under three categories: (1) functionality, which includes interaction dimensions, interface-content relationship, and levels of information process, and (2) cognition, which includes cognitive load, learner characteristics, and learning styles. They collectively contribute to the design of an effective interface, and (3) features which include the interface mode, such as using multiple sensory inputs, and locus of control, such as allowing learner or system control.

A design framework was proposed to examine the perceptual-conceptual and interface-content relationships in interface design. Our study suggested that the user's perceptions of an interface were influenced by the features as well as the functionality of the interface. The findings of our study indicated that learners became more perceptually engaged when they were exposed to the interface with multiple sensory inputs. Our study also showed that building affective interaction at the perceptual level can significantly enhance learners' perceptual engagement.

This study confirms research in cognitive performance and distributed cognitions that tools can influence human condition to think along a particular path (Sedig et al., 2001). The study highlights the need for understanding the cognitive engagement and the components that support the learner's cognitive interaction with the interface. The results suggested that cognitive load, spatial ability, and so forth could influence learners' self-efficacy and achievement in learning. Therefore, it is suggested that the software interface design should examine the cognitive factors and the impact it has on learners' learning to design interfaces that promote effective learning.

The chapter is significant at both practical and theoretical levels. Theoretically, it contributes to the understanding of the cognitive effects in human-computer interaction by identifying the relationship between cognitive factors and interface design. The perceptual-conceptual and interface-content framework has a theoretical significance as it delineates the relationships between interface and content, and between perceptual and conceptual information processes in terms of the three interaction dimensions. Practically, the chapter presents a new approach toward interface design by putting in perspective the cognitive and functional aspects in the design process. The framework proposed in

Table 2. Independent samples t-test

Independent Samples Test

		Levene's Test fo								
							Mean	Std. Erro	95% Confidenc Interval of the	
Change in self effi	Equal varianc assumed	55.367	.000	8.701	220	.000	4.615	.530	3.570	5.660
	Equal varianc not assumed			8.869	152.88	.000	4.615	.520	3.587	5.643
Cognitive load	Equal varianc assumed	3.540	.061	-10.58	220	.000	-5.4278	.5127	-6.4384	-4.4173
	Equal varianc not assumed			-10.51	203.12	.000	-5.4278	.51606	-6.4453	-4.4103
Performance	Equal varianc assumed	.050	.823	15.959	220	.000	4.0058	.25101	3.5111	4.5005
	Equal varianc not assumed			16.001	219.59	.000	4.0058	.25035	3.5124	4.4992

this chapter can help teachers, designers, and other related professionals to design and develop an effective human-computer interface.

Future research should apply the design framework to a larger population with more diverse background to validate the generalizability of the framework in other subject areas. Further research is needed to find out the impact of other cognitive traits such as field dependent vs. field independent on the use of and design in interface.

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KEY TERMS

Agent-Based Design Model: Agent-based design model consists of dynamically interacting rule-based agents. The systems within which they interact can therefore create complexity like that which we see in the real world. The model was developed through a simple conceptual form in the late 1940s, and it took the advent of the microcomputer to really get up to speed. The idea is to construct the computational devices (known as agents with some properties) and then simulate them in parallel to model the real phenomena. On some levels, agent-based models complement traditional analytic methods. Whereas, analytic methods enable us to diagnose and find solutions to a system, agent-based models allow us to explore the possibility of generating those solutions. This generative contribution may be the most mainstream of the potential benefits of agent-based modeling. Agent-based models also can be used to identify lever points, moments in time in which interventions have extreme consequences, and to distinguish among types of path dependency.

Cognitive Architectures: The concept of cognitive architecture originates from cognitive science related to the early days of cognitive psychology and artificial intelligence, as manifested in the general problem solver (Newell & Simon, 1963), one of the first successful computational cognitive models. However, cognitive architectures differ from traditional research in psychology in that work on cognitive architecture is integrative. That is, they include attention, memory, problem solving, decision making, learning, and so on (Byrne, 2003). The notion of cognitive architecture has been widely used in the gaming, intelligent tutorials, and the like. Cognitive architectures have been identified and integrated in the design of programming. For instance, in designing a math problem solving tutorial, the cognitive algorithm related to math problem solving should be identified, followed by an analysis of the sequence of behaviors to successfully carry out the math problem solving. The computational model of math problem solving thus reflects the structure of human cognition and a specific domain of knowledge. The cognitive architectures can be integrated in programs that help users perform simple calculations, make quantitative predictions, and so on. Designing interfaces that optimize human performance with the cognitive architecture in the program is one of the endeavors pursued by aspiring interface designers.

Cognitive Load: According to the cognitive load theory (CLT), three types of cognitive load exist: *intrinsic load*, *extraneous* or *ineffective load*, and *germane* or *effective load*. The intrinsic cognitive load refers to a cognitive load that is induced by the structure and complexity of the instructional material. Usually, teachers or instructional designers can do little to influence the intrinsic cognitive load. The extraneous cognitive load is referred to the cognitive load caused by the format and manner in which information is presented. For example, teachers may unwittingly increase a learner's extraneous cognitive load by presenting materials that "require students to mentally integrate mutually referring, disparate sources of information" (Sweller et al., 1991, p.353). Finally, the germane cognitive load refers to a cognitive load that is induced by learners' efforts to process and comprehend the material. The goal of CLT is to increase this type of cognitive load so that the learner can have more cognitive resources available to solve problems (Brunken et al., 2003; Marcus, et al., 1996).

Direct Manipulation: Schneiderman's (1982) theory of direct manipulation emphasizes manipulation through sensory perceptions including visual, auditory, haptic, and others. Direct manipulation employs real-world metaphors for objects and actions which make it easier for a user to learn and use an interface. Additionally, rapid, incremental feedback allows a user to make fewer errors and complete tasks in less time, because they can see the results of an action before completing the action (Iwata, 2003; Preece at al., 2002). Direct manipulation recognizes the role of both external and internal representations in the cognitive process. It facilitates information process through multiple sensory channels, the notion of which has been supported by several cognitive theories such as dual coding theory, cognitive load theory, and so on.

Dual Coding Theory: Paivio (1986) suggests that the input information is processed through multiple sensory channels. For example, the verbal information is registered through the verbal channel whereas the nonverbal information such as images is registered through the nonverbal channel. According to dual coding theory, there are three levels of processing pertaining to incoming verbal and nonverbal information: representational, associative, and referential. The representational process refers to the connections between an external object and internal representation of the object. The associative process means the activation of the information stored within the long-term memory. Depending on the input stimuli, the activation process can be either in the verbal or nonverbal (e.g., visual) system. The referential process is the cross-reference process between the verbal and nonverbal systems. Research on dual coding practices suggests that pictures can be coded both visually and verbally, whereas words are believed to be far less likely to be coded visually (Paivio, 1991; Rieber, 1994).

Human Perception: The human perceptual abilities include the range of visibility, perceptual focus, attention, and so forth. These abilities are further affected by the design elements embedded in the interface, that is, color, text size, text/graphic ratio, and others (Blake & Sekuler, 2006). Blake and Sekuler point out that perception is a biological process that "provides us with a useful view of the world, where useful means being able to interact safely and effectively within our environment" (p. 1). In a human-computer environment, this means focusing on the important information and ignoring the irrelevant. According to Blake and Sekuler, four interfaces have critically influenced the choice of perception. They include (a) constructive, (b) contextual, (c) interpretative, and (d) synchronizing interfaces.

Working Memory: Working memory is a theoretical framework that refers to the structures and processes used for temporarily storing and manipulating information. According to Baddeley and Hitch (1974), the working memory consists of two "slave systems" responsible for short-term maintenance of information, and a "central executive" responsible for the supervision of information integration and for coordinating the slave systems. One slave system, the articulatory loop, stores phonological information and prevents its decay by silently articulating its contents, thereby refreshing the information in a rehearsal loop. The other slave system, the visuo-spatial sketch pad, stores visual and spatial information. It can be used, for example, for constructing and manipulating visual images, and for the representation of mental maps. The sketch pad can be further broken down into a visual subsystem (dealing with, for instance, shape, color, and texture), and a spatial subsystem (dealing with location). The central executive system is, among other things, responsible for directing attention to relevant information, suppressing irrelevant information and inappropriate actions, and coordinating cognitive processes when more than one task must be done at the same time. Studies show that the working memory is very limited in both duration and capacity. The working memory typically stores about seven elements but normally operates on only two or three elements.