Interface Design: A Focus on Cognitive Science

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Abstract

This paper studies the issue of cognitive load theory and its implications to teaching interface design principles in a GUI or Interface Design course. The quality of interface design will increase effectiveness of human performance if working memory is emphasized. Cognitive science research in cognitive load raises interesting questions of an individual's memory load and its relevance to computer based models. It describes structures of information processing from long term memory, which stores knowledge and skills to using working memory that enable the individual to perform tasks that are embedded in a computer interface. This review focuses on the concept of cognitive load theory based on research by John Sweller and others in the field that brought this theory to the forefront. The issues of split attention and redundancy effects from information, spatial learning in real life situations versus computer simulation and exploration space control in reference to computer based systems is reviewed for enriching the interface design curriculum. This paper will review the issues of cognitive load theory and its relevance for developing computer based interface systems and models.

Keywords: Cognitive load, working memory, interface design, split attention, redundancy, performance

Processing of information requires the user to retrieve information from long-term and short-term memory. In recent years, cognitive science studies have focused on mental process of learning, memory and problem solving (Cooper, 1998). Cognitive load theory is a theory that describes learning structures of information processing involving long term memory which stores knowledge and skills on a permanent basis and working memory which perform tasks associated with consciousness (Cooper, 1998). The premise of cognitive load theory is that quality will increase if emphasis is given to the limitation of working memory (Cooper, 1998).

Long-term memory can hold an unlimited number of hierarchical organized elements known as a schema. The schema allows a person to retrieve sub-elements of information as a single element (Kalyuga, Chandler, and Sweller, 1998). The role of a facilitator is to transform a novice into an expert within a subject area or procedure. Much of the research in cognitive science measured the differences between expert and novice problem solvers (Cooper, 1990). It is suggested that a designer must look at the speed and accuracy of expert performers. The schema allows a user to categorize a problem according to a solution mode; however, novices that do not process a schema are unable to categorize a problem (Cooper, 1990). John Sweller's research suggests that effective materials enhance and facilitate learning by activating and directing cognitive resources on the activities to schema acquisition. According to Sweller, limited working memory makes it difficult to gather elements of information simultaneously. When multiple information elements interact, they must be presented simultaneously creating heavy cognitive load. The result of heavy cognitive load weakens the success of learning or performing tasks (Wilson and Cole, 1996).

Similar studies on cognitive load was conducted by Fred G. Paas who studied cognitive load for problem solving in complex cognitive domains such as computer programming, mathematics, and science. These domains are constrained by the limited cognitive process capacity of human memory (Paas, and Merrienboer, 1994). Studies by Paas measured effectiveness of performing statistical problems of a conventional strategy with two alternative strategies using worked-out problems and partly worked out problems. Paas hypothesized that the worked and completion conditions would yield less mental effort and lower instructional time than conventional methods (Paas, 1992). Paas's study concluded that the use of partly or completed worked-out problems is more efficient knowledge base for problem solving than those resulting from instruction emphasizing conventional problems (Paas, 1992). In a later study, Paas, and Merrienboer conducted a similar experiment that more effective and efficient transfer performance is reached with less time and less mental effort for training than would students in conventional conditions (Paas, and Merrienboer, 1994).

1. SPLIT ATTENTION AND REDUNDANCY

Human working memory has an impact in learning complex tasks. The effectiveness of design is partly dependent on managing unnecessary cognitive load (Yeung, 1999). Redundant information is an obstacle to schema acquisition where the person processes nonessential information. Consequently, nonessential information increases cognitive load. The split attention affect occurs when people are required to divide their attention and mentally integrate multiple sources of information resulting in less effective acquisition of information. On the other hand, if the person was presented the same material in a physically integrated form, the integrated format reduces working memory load (Mousavi, Low, and Sweller, 1995). The studies by Mayer in 1989 and Gallini in 1990 showed discrete text and unlabeled diagrams were ineffective compared to text and labeled diagrams (Mousavi, Low, and Sweller, 1995). Computer based systems requires the interface design to maximize human performance or interaction with the system. Cognitive load is an important factor when designing interfaces. Measuring the effects of cognitive load to the interface can provide and unique insight to effect of human interaction and performance outcomes.

The issue at stake is how a person benefits from integrated information. Expert users may not benefit from integrated approach where they are reluctantly processing unnecessary information lowering comprehension. However, when lower level users are given an integrated format, their mental resources are available for comprehension reducing split attention (Yeung, 1999).

Cognitive load theory incorporates a variety of procedures on the assumption that working memory is limited and skilled performance requires schemas held by long term memory. The information presented to people and the activities required should be structured to eliminate any load on working memory and increase access to schemas. Multiple sources of information directed to people may find one or more of the sources ineffective by itself (Kalyuga, Chandler, and Sweller, 1998). Individuals achieve understanding only by integrating the sources together. An example would be a circuit diagram with no text. Alone the diagram is not useful unless the text and the diagram are mentally integrated. The two sources of information physically integrated reduce the need for mental integration. Consequently, working memory load is reduced, freeing up resources for schema acquisition (Kalyuga, Chandler, and Sweller, 1998). The source of information retrieved depends on the nature of the information and the level of expertise of the individual. A novice group of individuals may have the basic concepts required to understand the information such as the principles of circuit diagrams. However, they may have insufficient knowledge or an acquired schema that deals with the information. On the other hand, experts have sufficient knowledge of circuits from training and exposure to electrical equipment. They have experience reading circuit diagrams where they developed a schema that explains the function of each type of circuit. In this case, text on the circuit diagram is considered redundant for these users since they acquired a schema. The expert user may try to ignore the text but may have difficulty ignoring it resulting in redundancy (Kalyuga, Chandler, and Sweller, 1998). A computer interface with integrated text and information may result in redundancy for expert users where they prefer to perform certain tasks using shortcuts. Split attention effect occurs when multiple sources of information are difficult or impossible to understand by itself. The information must be integrated mentally or physically for the information to be understandable. Mental integration creates heavy cognitive load. The redundancy effect occurred where multiple sources of information are understandable by themselves where each source provides similar information but in a different form. Therefore, unnecessary working memory load is the result of people having to split their attention between sources of information. Expert computer users can suffer split attention effect if interfaces of software tools design for a specific group or audience can be become ineffective lowering performance levels.

2. MODALITY EFFECTS

People have multiple working memory stores, channels, or processors associated with auditory or visual processing. The auditory and visual system processes different types of information independently (Mousavi, Low, and Sweller, 1995). The independence of the two systems affects the process of working memory. Presenting information in a mixed auditory and visual mode determines how working memory processes information. For example, results were worse when people were asked to learn a series of words presented in auditory form rather than in visual mode. Hearings words while listening to speech interfered with memory of words than reading them. Therefore, more capacity is available when two modes are used together (Mousavi, Low, and Sweller, 1995). Effective cognitive capacity can be increased and performance levels can be enhanced when auditory and visual working memory is used. Integrating audio and multimedia to the interface can allow a user the option to perform difficult tasks without increasing cognitive load in working memory.

3. PROBLEM SOLVING THE INTERFACE

Mastering a difficult interface is a form of problem solving. Some individuals adapt and learn quickly while others take more time to build their mental model of the interface. A study using a computer spreadsheet application to compare direct instruction versus discovery learning used three groups of participants where one group was given a tutorial manual to the computer application. The second group was the problem-solving group was given some structure but allowed discovery learning. The third group was the exploration group had the least amount of structure and created their own problems to solve. This study by Charney et al. in 1990 measured tutorial-based learners who were given the problems with the solutions as worked examples. The problem-solving group had less structure and more discovery learning to solve the problems, where the third group had no structure (Tuovinen and Sweller, 1999). The problem-solving group took the longest amount of time but resulted in the fastest mean time for reaching the correct solution using the spreadsheet application. The exploration group became more competent in a limited range of the application features than the interactive tutorial and problem solving groups (Tuovinen and Sweller, 1999). The studies revealed that cognitive load is greatest on problem solving and exploration groups where the tutorial based worked examples group cognitive load is reduced because people do not use mental resources in defining task parameters (Tuovinen and Sweller, 1999). Many computer-based tools come with tutorial-based instruction. Though it reduces cognitive load, it does not necessarily improve mastery of the application.

4. SPATIAL LEARNING AND COMPUTER-BASED MODELS

Many studies have researched the use of computer models as a tool for spatial learning (Rossano and Moak, 1998). An individual's spatial representation has an orientation in memory that corresponds to a map. A person aligns his or herself in an environment equal to a preferred orientation; the person usually makes accurate judgments. When the person is oriented differently from the preferred state, it results in judgment errors (Rossano and Moak, 1998). Computer models simulate direct environmental experience as a spatial learning tool where computer simulated environments allows the person to freely navigate through the simulation. The issue in the study of orientation specificity is the actual and simulated tests of orientation. Rossano and Moak refer to a study conducted by Thorndyke and Hayes-Roth in 1982 where participants were located in a specific environment and were required to indicate the direction to other points. In a simulated test, the person was seated at a table imagining being in another location. The person in the simulated test performed worse than the person in the actual environment. This is a consequence of the cognitive load resulting from having to imagine spatial location (Rossano and Moak, 1998). In this situation, cognitive load increased as more interactive elements are held in working memory simultaneously. Simulated tests are higher in cognitive load than actual tests (Rossano and Moak, 1998). The actual test provided the location and facing direction reducing the amount of working memory. Therefore, studies using computer models revealed low results. The learning from a computer model is less engaging than direct experience (Rossano and Moak, 1998). In a real environment, a person uses multiple sensory input. The sensory inputs connect to stronger accessible memories than when using a computer model. The concern in using a computer model is the mental burden on the person. Rossano and Moak conducted a study to prove that computer models would eliminate orientation specificity and result in improved performance (Rossano and Moak, 1998). The study used a computer model of a college campus where users were given an orientation test with a view visually presented on a computer screen. The participants did not have to imagine the view. A second group studied maps of the campus. The computer group acquired survey knowledge of "understanding configurable relations among elements of the environment" (Rossano and Moak, 1998, p. 486). Other studies have shown that memorizing a map improved the person's direction and distance judgments compared to those with directional experience (Rossano and Moak, 1998). Spatial knowledge shows people slowly construct a survey representation in long-term memory. With the Rossono and Moak study, it was hypothesized that the computer model experience would develop more slowly than the direct experience. Many of the results were inconclusive. Further studies using computer models enhanced the computer experience using a walk through software to create realistic three-dimensional representations. The results of these studies were inconclusive where computer exposed subjects and map-exposed subjects showed no differences (Rossano and Moak, 1998).

5. COGNITIVE SCIENCE INFLUENCE

Working memory for people who engage in computer-based tasks requires holding information in the mind several seconds during cognitive processing. The overload of memory creates performance errors. An effective use of working memory required to conduct computer-based tasks require alternative interface designs and computer-based training protocols (Gevins, Smith, and Leong, 1998). For example, the studies showed that working memory load increased because of the demands placed on the working memory resources by computer-based tasks (Gevins, Smith, and Leong, 1998). This study is extremely important for the research of human computer interaction.

In cognitive load theory, people will process materials or tasks in different ways. If the person acquires appropriate automated schemas, cognitive load will be low freeing up working-memory resources. However, if elements of the material that require processing must be considered an individual element in working memory because there is no schema available, then cognitive load is high (Tuovinen and Sweller, 1999). If the cognitive load is high then the person must deal with a large number of interacting elements.

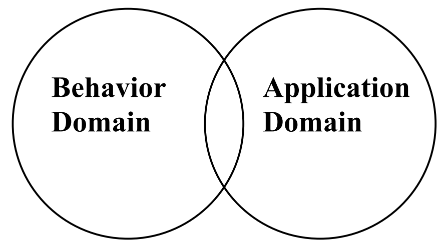
Computer based systems uses multi-media hypermedia technology to simulate and demonstrate virtual reality for exploratory learning purposes. This allows individuals to explore concepts and knowledge. The key is to limit the exploration space needed to control cognitive load (Kashihara, Kinshunk, and Oppermann, 2000). Exploration space control (ESC) consists of "information space and exploration operations given to learners at that moment" (Kashihara, Kinshunk, and Oppermann, 2000). The space is the extent of information resources including the content and ways to access the information such as the "search" and "selection" tasks. The control is to restrict exploration tools on the interface to tailor the information to be presented.

ESC is a self-directed mental activity where the users find out and comprehend concepts and knowledge. It is not the same as browsing or scroll reading, it can apply conceptual knowledge to problems and situations to acquire cognitive skills. According to the Kashihara, Kinshunk, and Oppermann study, individuals need to be free to explore by themselves to enhance their performance by exploring various paths. However, individuals tend to make heavy cognitive efforts to search for information. Hypermedia, simulated learning systems, and simulation-based training systems require the individual to explore. The two sides to this concept is to allow the people to explore as much space as possible, to use a many paths and efforts to explore, and to prevent people from reaching many paths to prevent confusion. The key is to determine the level of exploration space required of the interface.

Some of the design techniques used for ESC is embedding information based on performance goals, limiting information resources to prevent difficulties of individuals deciding which information to access, and presenting the information (Kashihara, Kinshunk, and Oppermann, 2000). In essence, ESC puts cognitive load in perspective with the design of the interface and its content.

When designing a computer interface for people to use application tools, a designer must ensure that the material on the computer screen or in the manual is physically integrated where possible and has no redundancy (Sweller, 1999). The equipment can lead to split redundancy and split-attention effects when learning to use the interface occurs with a manual (Sweller, 1999). To eliminate these affects, Sweller states that all material could be placed on a computer screen. Auditory instructions on how to operate a computer screen or a software application may be better than reading the instructions (Sweller, 1999).

The cognitive issues in interface design put emphasis on integrating the two domains of GUI development—the behavior domain, which focuses on human user interaction with respect to the design of the human interface and the application domain that focuses on the software life cycle development. The integration of the two domains should be incorporated in a course devoted to GUI or interface design.



Software Development and Interface Design Context Model

6. CONCLUSION

Issues of cognitive load address the concept of memory overload. Computer software designers have to take into considerations the users expertise in respect to memory load when designing an interface. To avoid split attention effect of the novice user it is effective to integrate the content into the interface, which may lead to redundancy effect for expert users. With the proliferation of technology in business, computer-based systems are growing and interfaces need to be designed with cognitive load theory in mind. However, computer based tools depends on the level of expertise of the user. As referenced from the literature, spatial learning and a balance of exploratory space control is needed to manage cognitive load. Technology in the work force is growing and development of content should be embedded in the interface design process. Cognitive science has provided software designers an issue that must be addressed when developing an effective interface to be used as an everyday tool that will increase work performance. Studies in cognitive load enhance the issues of human computer interaction and decision support systems. Teaching cognitive science principles in the traditional GUI development class in the Computer Information Systems curriculum will broaden the student's knowledge and skill as an interface designer and programmer. The basic principles of GUI design are just as important; however, presenting cognitive science principles in an interface design course resulted in higher creativity and problem solving in the final projects. Students embraced the issues raised in the lectures and incorporated them in their projects. The concept of theory introduced in this course has made these students into designers rather than traditional GUI programmers. Feedback from nontraditional students in the field of software development embraced the theory in their work. Human behavior and cognitive science have much to offer in this discipline. It is an asset to our discipline that is normally considered technical; nevertheless, it is an important component to screen design.

7. REFERENCES

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