Human Factors in Computing: The Influence of Multimodal Design on Long-Term L2 Vocabulary Retention

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Abstract

This study investigates the influence of multimodal software design on long-term second language vocabulary retention. Our primary hypothesis posits that employing a multimodal design in second language acquisition (SLA) application development will lead to an increase in explicit semantic encoding of second language (L2) words in long-term memory (LTM) and subsequently an increase in long-term word retention. We also demonstrate that speech recognition has evolved sufficiently to be applied as a language learning tool. We investigate many of the existing psychological theories and software engineering paradigms that support our hypothesis. Finally we present a new software engineering model, C-CAD, which responds to a need for a more cognition-centred approach to software design.

Keywords

Second Language Acquisition, multimodal design, speech recognition, vocabulary retention, C-CAD.

INTRODUCTION

Human-Computer Interaction (HCI) is an area of research with the primary objective of investigating the impact human factors have on computing, and as such, it plays an increasingly important role in the development of usable computer-based applications [Newman & Lamming, 1998; Preece et al, 1994; Cohen et al, 1997; Groot, 2000; Plass, 1998].

The present study demonstrates how human-computer interaction attempts to move beyond solving problems of traditional limiting factors, such as storage or speed of computation, by improving the user experience. It is these types of efforts that have led to the advent of user-oriented tools such as the graphic user interface (GUI), now central to the use of most popular operating systems.

Our study examines one such development in computing: multimodal interaction.

Multimodal design attempts to integrate two or more modalities[1] in the hope of providing a more flexible user interface. The ability to control most computer-based applications via keystroke entry (Control-S to save in Microsoft Word) and by graphic manipulation (Click on File and drag the mouse pointer down to Save) is a perfect example of how multimodal interfaces can increase user performance. However, most expert users of an application would find constant search through various submenus of commands frustrating, and would most likely prefer a single mnemonic keyboard command. Catering for novice and expert user levels during software design is a primary example of user-centred approach, a basic principle of HCI.

A traditional constraint upon multimodal design has been designing with context in mind [Norman, 1990]. Some operations naturally afford one particular design whilst others may not. How frustrating would it be to create an image electronically using key-level mode only, without the aid of a mouse? Likewise, with the speed and proficiency most users have attained at typing electronic documents, what a step backwards it would be to use an electronic pen or stylus to

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[1] In our study, 'mode' refers to an input modality such as voice, key-level or graphic manipulation (i.e. with a mouse). Another distinction that we make is between unimodal and multimodal. In the present study keystroke entry and graphic manipulation modes typical of GUI enhanced systems are treated as a single unified mode. However, speech and keystroke entry are considered to be multimodal.

create the text!

These same considerations must be taken into account (even more so) when designing voice-enabled applications. Considerable effort in predicting human speech behaviour goes into the development of any telephony system capable of intelligent speech recognition and dialogue control [Norman, 1990; Preece et al, 1994]. Even today we are unable to capture all of the complexities natural language presents. Without taking human factors into account during development, many (if not most) speech recognition systems would simply not be able to function with any degree of success.

Today, speech recognition technology is more accessible than ever. We use it in mobile phones, when we call the operator for assistance, and sometimes to control various features of our computers. We can simulate speech at near human quality in scores of languages from around the world, allowing visually impaired users a greater amount of personal autonomy. We can dictate entire documents without the assistance of a secretary or ever having touched a keyboard.

Speech recognition and related technologies will have a major impact on computing in the coming years. In what way and to what extent remains to be seen, but already we can envisage some direct applications of this technology.

Second language acquisition (SLA) is one such example. This area of research is concerned with not only the instruction of foreign language, but also the cognitive aspects of learning which are essential to the learning process. Speech recognition complements SLA perfectly in that it allows users to interact with the computer in much the same way as they would hope to with a human being. As SLA itself is deeply rooted in psychological theories on memory, language and cognition, it stands to reason that any computer-based application to be used in this area of research must be *aware* of these concerns.

Use of computers as a tool for assisting instruction is not new. Computer-Aided Language Learning (CALL) is an area of research whose primary goal is to investigate the use and impact of computers in learning environments. For second language (L2) learners, CALL applications are frequently used for improving vocabulary acquisition as well as grammar and sentence-level production. Voice-enabled CALL applications are the next logical progression. However, it is imperative that design plays an integral, almost determining, role in the development of such applications. As mentioned previously, design is the key to success in any voice-enabled system [Oviatt et al, 2000].

This study has chosen to concentrate on a small piece of the puzzle: multimodal design. Moreover, we investigate the impact of multimodal design on L2 vocabulary acquisition through a combination of traditional input modes and speech recognition.

We submit that multimodal design should have a net positive effect on L2 vocabulary retention given the empirical evidence and cognitive theories presented within this paper.

At present there is a considerable lack of empirical data examining the effectiveness of multimodal design. Furthermore, there is little to no evidence of the impact of multimodal design on sensory processing. Developing guidelines for producing effective multimodal CALL applications will require accumulating predictive data on human cognition [Oviatt et al, 2000] and a new software development model capable of taking full advantage of this information.

From a theoretical perspective, research regarding the characteristics of good second language learning suggests that language comprehension requires that listeners actively draw inferences about the input they receive [Groot, 2000; Brown, 1987; Hulstijn & Laufer, 2001; Lotto & de Groot, 1998]. Likewise, feedback that is informative, positive and which guides users towards finding a solution can greatly assist in the language classroom [Robinson, 1991].

An important aspect of the present study is our examination of the effect of multimodal design upon long-term word retention. It is our hope that our findings may improve foreign language instruction and CALL development, as well as contributing to our understanding of SLA.

Finally, in the hope of providing a framework in which to produce "user aware" software, we argue for a new software development model capable of integrating elements of human cognition into the production of more intuitive and effective user-oriented software.

C-CAD: A COGNITION-CENTRED APPROACH TO SOFTWARE DESIGN

In her discussion of software design models currently used in developing multimedia applications for foreign instruction, Plass [1998] calls for the realisation of a new hybrid software development model. In response to her opening criticism that "… issues in the design of the user interface are often neglected in the development of instructional software", we have conceived a software development model that incorporates the advantages of both software engineering and cognitive science. We have coined this new hybrid model C-CAD.

C-CAD (Cognitive-Centred Approach to Design) is based upon well-established software engineering principles and cognitive theories. As a hybrid model, it aims to integrate and extend the rapid prototype model and User-Centred Design (UCD) approach [Gould et al, 1987]: two of the most highly supported software design models in usage today [Schach, 1999].

By adhering to rigorous software engineering procedures, developers can expect to produce well engineered software that exhibits many of the classical quality attributes of software engineering such as functionality, maintainability, scalability, portability and useability [Schach, 1999]. Through constant attention to human factors, developers can create more intuitive, useable software [Preece et al, 1994; Cohen et al, 1997].

The primary justification of the proposal for this restructured approach to software design is that it affords the consideration of cognitive aspects inherent in human-computer interaction throughout the requirements, specifications and design phases of software development. We contend that a structured hybrid model would address many of the criticisms made by Oviatt et al., in their call for a software design framework that caters for human factors [Oviatt et al, 2000].

The benefits of proscribing a hybrid model such as C-CAD are numerous. Firstly, the use of theories and empirical evidence grounded in cognitive science promotes the examination of human factors in human-computer interaction. Second, as this investigation occurs during the preliminary stages of software design, *hidden* human factors become apparent at a much earlier stage during development. This is essential to any project where increased productivity, reduced costs and risk mitigation are of primary concern [Schach, 1999].

Whilst various UCD models, initially proposed by Gould et al. [1987], have enjoyed widespread success and enormous support amongst HCI designers, they rely heavily on focus groups, software review stages and post-development user feedback: all of which fail to elicit unconscious processes which occur during user testing. They are significant improvements on rapid prototyping models that attempt to determine software requirements without preliminary user consultation, and which fail to take into account the importance of cognition in task analysis and completion.

What sets C-CAD apart from many other software development models, such as RAD (Rapid Application Development), is that there is a clear emphasis on the importance of cognition throughout development.

C-CAD is being used effectively in the present study to address many of the design issues at the core of interactive system design [Newman & Lamming, 1998].

MEMORY, LANGUAGE AND COGNITION

Understanding how knowledge is stored in memory is essential to our comprehension of cognition and the impact of software design upon the processing of new information. The term *memory* cannot be seen as a mere reference to our ability to encode and recall facts such as telephone numbers.

Memory is a multifaceted structure, segmented along functional boundaries that allow us to efficiently process information. Whilst these highly individualised *components* serve specialised functions, they remain tightly interwoven, like fibres in a garment.

As the aim of our study is to examine the impact of multimodal design upon L2 word retention, it is imperative that we examine the role of memory and cognition in user task-performance.

Today, it is customarily understood that two kinds of memory exist: explicit and implicit. Further general levels,[2] which are imperative to our discussion, can be represented within these two categories.

Explicit memory

Facts and memory of events are of an explicit-declarative nature. When memorising information such as words in a foreign language, we are exploiting explicit memory or conscious recollection. Explicit memory is activated when

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[2] In this paper we will not discuss the various sensory registers or task-specific components of memory such as allophonic registers [63].

we consciously attempt to retrieve information from LTM [Westen, 1999].

Explicit memory can be semantic or episodic. Semantic memory refers to knowledge or facts. Episodic memory consists of memories of particular experiences and is also responsible for the association of thoughts or feelings with prior events [Westen, 1999].

Implicit memory

There are two major forms of implicit memory: procedural and associative. Procedural memory encompasses memories of actions, such as buttering a slice of bread.

Associative memory encapsulates mapping between distinct pieces of information accumulated through prior exposure to particular events. For example, associative memory may tell us that "people who cry are unhappy". At no point is this fact retained in memory as it can be inferred through association. Mathematically, this can be seen as an example of first order logic, A = B = C, therefore A = C. Association works by allowing new stimulus to prime previously stored knowledge. Implicit-associative memory can also act as interference, inhibiting the processing of new information.

Continuing with our previous example, most people have difficulty understanding tears of joy, immediately assuming that the person is upset. The perception of tears primes information from previous experiences which relate tears to unpleasant events. It is this priming that leads us to question the emotional wellbeing of the other person.

The explicit/implicit dichotomy is helpful in relating the way knowledge is retrieved and expressed. Through our discussion we shall demonstrate that understanding this dichotomy during the development of user-oriented software, such as computer-aided learning (CAL) tools, is essential to software engineering practices.

Information retrieval

In order to recall information from LTM into working memory (WM), cognitive schema must be in place for the storage, categorisation and subsequent retrieval of information [Westen, 1999]. It therefore stands to reason that supporting the creation or restructuring of mental models is essential to deep learning and knowledge retrieval. This is a fundamental problem L2 learners face when learning a language conceptually different to their own native language (such as tonal (Cantonese) and non-tonal (French) languages).

Why focus on explicit memory rather than implicit memory?

In order to facilitate the establishment of new conceptual models, we contend that L2 learners should avoid using implicit-associative memory as it encapsulates the new information within a framework that is essentially dependent upon prior knowledge, i.e. L1 (first language) knowledge. In the case of language learning this would prevent the learner from developing new and long-standing cognitive representations of the target language.

Evidence shows that implicit and explicit memory are distinguishable by the type of cognitive processing which occurs within the various regions of the brain. Neurophysiological evidence claims that explicit-semantic memory occurs in the medial regions of the brain, whereas implicit memory such as associative memory occurs in the frontal lobes [Westen, 1999]. Through the use of associative pairs (such as bilingual lists) in language instruction, the designer places a considerable strain upon WM as well as forcing the student to rely upon implicit-associative memory.

As WM (also referred to as STM) is known to contain and process only temporary, mostly conscious information [Miller, 1956], at no real stage does any cognitive processing occur in the hippocampal region of the brain, responsible for processing and storing *world* knowledge (i.e. the words to a national anthem). Therefore in order to ensure that information is stored successfully in LTM, increased efforts must be made to stimulate the hippocampal region of the brain at the time of encoding [Westen, 1999; Miller, 1956].

This claim is supported by Craik and Lockhart's theory of *Levels of Processing* [Lockhart & Craik, 1990; Craik & Lockhart, 1972], in which it is proposed that the more cognitive processing a cued stimulus receives, such as the presentation of a novel word, the deeper the level of processing. This theory posits that there are various levels of processing at the sensory, working (WM) and long-term (LTM) stages of memory.

In the case of SLA, the deeper the processing, the greater the likelihood that L2 information will be retained. Craik and Lockhart also stipulate that information with visual and echoic representations (such as images and spoken word), or information which is being consciously attended, will lead to deeper processing. This is essentially due to the fact that these additional pieces of information are likely to have associations with previously stored knowledge, and therefore act as storage and retrieval stimuli. Modern GUI (graphic user interface) design owes a large portion of its success to the *Levels of Processing Theory*.

Networks of association

In stressing the importance of moving beyond a reliance upon associative memory as a means of storing new information in LTM, we note that association is in fact crucial to the act of remembering. Pieces of information already stored in memory form networks of association: groups or clusters of interconnected information.

The basic units of these networks are nodes that can represent any of the sensory stimuli from taste to emotion, to images. As nodes are highly related to their neighbour, their inter-connective pathways create complex and highly associative networks, similar to that of a spider's web.

One theory that attempts to explain the workings of networks of association is called *spreading activation* [Collins & Loftus, 1975]. According to spreading activation theory, activating one node in a network triggers activation in closely related nodes. In other words, a stimulus that triggers a firing in the neural circuits will spread the activation to other related information in nearby memory.

Increased association between nodes leads to a broadening of neural pathways. Through prior association of two event stimuli, a 'road' between the two nodes is built, and if the association continues to grow, that road will be 'widened' to ensure rapid neural transition between them [Westen, 1999]. If, on the other hand, these internodal connections fall into disuse then *decay theory* stipulates that storage and retrieval capacity of this or related information will be dramatically affected [Westen, 1999].

Decay theory and networks of association go a long way toward supporting our study's primary hypothesis. Multimodal interactive environments typically lead to a greater number of event stimuli being provided during semantic encoding [Oviatt et al, 2000]. Processing of each cued stimulus results in the excitation of various nodes and the subsequent activation of associated maps within the neural network [Westen, 1999,4]. This in turn leads to faster retrieval of information stored in LTM [Lotto & de Groot, 1998; Chun & Plass, 1996].

The transference of multiple stimuli per presented knowledge item (i.e. L2 word), will consequently result in the preservation of neural pathways [Collins & Loftus, 1975; Wixted & Ebbesen, 1991; Westen, 1999; Anderson, 1995; Clark & Clark, 1977; Shuren et al, 1996], and assist later retrieval of information.

Considerable research supports the theory of spreading activation [Westen, 1999; Nisbett & Wilson, 1997]. According to many contemporary models, each time a thought or image is perceived, primed, or retrieved from memory, the level of activation of the neural networks that represents it increases [Westen, 1999]. Whilst difficult to corroborate, PET studies investigating the hippocampal region of the brain indicate this may indeed be the case.

Forgetting newly acquired knowledge is arguably a language learner's greatest dilemma. Therefore, increasing long-term vocabulary retention is essential for improving L2 language proficiency. Researchers have recently refined Ebbinghaus's forgetting curve [1885], which posits that the relation between memory decline and length of time between learning and retrieval is logarithmic. Essentially, this means that the rate of forgetting is initially very high but eventually becomes very low [Wixted & Ebbesen, 1991].

Interestingly, this forgetting curve seems to apply whether the period of time is hours or years. Increasing initial study-time increases retention, but forgetting occurs at the same rate. As increased study shifts the curve upwards, but does not change the rate of forgetting [Westen, 1999], so should increased exposure to semantic information during language learning.

Whilst we may not be able to reduce the rate of decay in explicit-semantic memory, we can hopefully increase the rate of initial and subsequent retention through the practices already outlined.

Word associations

Word associations are interesting for what they reveal about meaning. They suggest that semantic components play a central role in the process of word selection. Words are selected on the basis of their semantic procedures, and these in turn call upon component procedures that test for the applicability of words to situations. The evidence from word associations suggests that these component procedures are relatively separate mental operations [Clark & Clark, 1977].

Therefore retrieval of information uses semantic procedures, yet their eventual use is decided by implicit procedural calls, evaluating the applicability of the returned result to the current context. Again, this suggests that efforts to improve retention and later recall should concentrate on improving semantic storage of information.

Further evidence in support of this assumption resides in the study of divided attention (DA).

Craik & Govoni [1996] showed that DA was associated with large reductions in memory performance. In support of their findings, they point to evidence from neuropsychology and neuroscience which suggest that pathways involved in retrieval overlap substantially with those involved in perception and storage of the same type of information.

Results provided by Baddeley et al. [1984] suggest that retrieval processes are substantially automatic. Unlike encoding processes that place a heavy demand on attentional resources, it appears that retrieval can proceed without such resources.

In the studies conducted by Baddeley et al. [1984], when attention was divided at encoding, memory performance dropped substantially, but concurrent reaction time was slowed by a relatively small amount. DA at retrieval resulted in comparatively slight drops in memory [Craik & Govoni, 1996].

Instructions to emphasise the memory task had a large effect on memory during encoding, but none during retrieval. The result points to the consciously controlled nature of encoding processes and the relatively autonomous nature of retrieval.

Encoding specificity

The fact that ease of retrieval depends on the way information is encoded and later retrieved is known as the encoding specificity principle [Tulving & Thomson, 1973].

According to Tulving [Tulving & Thomson, 1973; Craik & Tulving, 1975], memory is a by-product of the normal processes of perceiving and thinking. This process instantiates neural pathways of experiences as they occur. When people remember, they simply reactivate the same neural networks that processed this information in the first place. If the circumstances at encoding and retrieval are similar, the memory is more easily retrieved because more of the neural network that represents it is activated [Westen, 1999].

For example, material from lectures is easier for a student to remember if s/he is sitting in a similar position as when s/he first heard the information. Likewise, trying to find lost keys is assisted by attempting to visually reproduce the environment in which you believe you have misplaced them. Having the same context during encoding and retrieval facilitates recall because the context provides retrieval cues, stimuli or thoughts which are similar to those used to initially encode the information [Westen, 1999].

The encoding specificity theory states that items are encoded in a highly specific way, and effective retrieval cues must reflect that specificity [Madsen, 1991]. According to Kolers [1973, 1979], a necessary overlap between encoding and retrieval occurs. Kolers points to the importance of context during encoding and retrieval of information. “Recognition is achieved by virtue of the correlation between the operations carried out on two encounters with a stimulus event. The more similar the operations, the readier the recognition.” [1973]. This is not surprising since encoding and retrieval processes may be qualitatively similar or even identical, despite the fact that they are carried out with different goals in mind [Craik & Govoni, 1996].

The notion of a retrieval mode is also supported by recent evidence from PET studies. Studies indicate that the active attempt to retrieve information is associated with activation in right frontal regions, regardless of whether memory targets are present [Kapur et al, 1995; Tulving et al, 1994].

The suggestion is that memory encoding processes are essentially those involved in perception and comprehension of external events. It follows that elaborate processing can further augment encoding. Retrieval is initiated either by the presentation of an explicit retrieval cue, by self-generated cues in response to a general memory query (for example, "please recall the words from the list in reverse order"), or simply by stimuli encoded in the normal course of perception.

Elaboration

Another principle that supports our claim that an interactive multimodal design in CALL applications will lead to an increase in long-term L2 vocabulary retention is the notion of elaboration [Craik & Tulving, 1975]. Elaboration states that the retention of new information depends on the amount and quality of attention that individuals pay to various aspects of words. Rich (qualitative) and numerous (quantitative) associations with existing knowledge (e.g. in the form of establishing similarities and contrast between old and new information) increase the chances that the new information will be retained. In essence, processing new lexical information more elaborately will lead to better retention than if it had been processed less elaborately [Lockhart & Craik, 1990]. Multimodal, speech-enhanced interfaces are prime examples of media-rich environments that should consequently lead to better encoding and better information retention.

COMPUTER-AIDED LANGUAGE LEARNING

The use of computers as an educational tool is not a recent practice. Computers have been used as teaching aids for almost half a century [Dunkel, 1991]. Computer-based testing (CBT) and computer-adaptive testing (CAT), despite some early criticisms [McNamara, 2000], are primary examples of the successful integration of computer-aided learning (CAL) tools into curricula [Madsen, 1991]. However, CAL has yet to exploit perhaps the most natural means of communication, human speech. Furthermore, the slow uptake of speech technology in CAL tasks is even more surprising given that natural speech is an integral element to general instruction and the process of learning [Lewis, 1993].

Lewis' criticisms of the infrequent use of speech technology in CAL applications [Lewis, 1993] are more poignant today than when first written, given the lack of accessible voice-enabled systems a decade ago. From a technological point of view, there appears to be very few valid reasons as to why significant efforts to incorporate speech recognition in CAL curricula should not be undertaken.

An obvious advantage of speech recognition and synthesis within the CALL paradigm is the flexibility it can deliver to language instruction. Software designers will be able to create and edit speech dynamically, reduce audio recording hours by eliminating the use of pre-recorded dialogue, and allow users to customise the voice type they are presented with, should they feel uncomfortable or anxious with the one presented [Onwuegbuzie & Daley, 2000]. Allowing students to produce spoken natural language through the use of text (Text-to-Speech, TTS) may also lead to greater self-confidence [Johnson, 1991], which is linked to an increase in knowledge retention [Johnson, 1991; Westen, 1999].

Theorists such as Vygotsky [1962, 1978] claim that when second language users communicate with an interlocutor with the mutual goal of understanding one another, both partners negotiate the meaning of their message by modifying the interactional structure of the conversation. As a result of these interactional modifications (negotiations), aimed at achieving mutual comprehension, L2 users manage to understand aspects of language beyond their current level of competence.

If comprehension of linguistic input is a necessary condition for second language acquisition then interactional modifications, through which communicators strive to understand one another, contribute to SLA processes.

There are other benefits of CALL to consider. Computer-mediated communication differs in important ways from communication mediated through other means. Students who gain expertise in task-based computer environments can experience an increase in self-confidence and status amongst their peers. According to Brown and Ellis [Brown, 1987; Ellis, 1985], confidence is an essential element of L2 acquisition.

However, the way that teachers organise classroom/lab-based computer interaction, and the problems they devise, affects the manner in which people interact with computers. For example, the aim of a specific exercise may be to correct grammatical errors in a sentence, or involve students in a discussion about the meaning of a particular passage of text. Rich language use will not necessarily result by simply introducing computers into a classroom [Johnson, 1991].

Careful consideration must be made when incorporating CAL tools into language curriculum. As an example, research has shown that computer activities can potentially isolate students, stifle their creativity and focus their attention on unimportant elements of language out of context [Johnson, 1991].

Abraham & Liou [1991] note that active language participation in small groups stopped as one member typed the response. This is similar to doctor-patient conversations whereby the patient waits for the doctor to hit `ENTER` before continuing with the conversation [Newman & Lamming, 1998]. The obvious change in mode had a dramatic effect on language participation.

When correctly employed, studies have shown that the use of CALL applications in L2 learning groups stimulates interaction amongst members, prompting them to interact with each other to a greater extent in the target language [Abraham & Liou, 1991]. Initial findings by Piper [1986] have also revealed that this may in fact lead to an increase in language competency.

At present the majority of CALL applications interested in SLA rely upon key-modal interfaces for expressing communication intent [Searle, 1969]. We submit that communication intent, which claims to provide the underlying principles of speech acts, is best supported by the use of speech recognition and voice synthesis: their ability to simulate spoken language is unsurpassable.

Voice-enabled software will allow for significantly more freedom in the types of dialogue created by the user. In the case of CALL tools, the user will also gain invaluable experience in actively producing the acquired knowledge which typically only occurs during heightened periods of interaction.

MULTIMODAL DESIGN

To date, there is limited research on the impact of different interactional modes of communication on cognition. Recent SLA research has primarily concentrated on pedagogical aspects of instructional methodology [Hulstijn, 2000]. Recent research by Oviatt et al. [2000] shows an increasing trend towards examining how input modes are integrated in voice-enabled application design, and their impact on the overall effectiveness of software design in human-computer interaction.

A frequent complaint levelled at speech recognition systems is that they do not adapt well to the unique characteristics of the user. Marked accents and suprasegmental features such as prosody have proven to be obstacles in developing user-friendly voice-enabled systems [Schneiderman, 2000]. However, a multimodal approach to design would dispel many of these criticisms by integrating modes in a way that they appear compensatory. With constant work being undertaken in the field of user adaptation, it will not be long before intelligent agents render truly speaker-independent systems a reality, but they will be compensating for the user's task-performance ineptitudes [Oviatt et al, 2000].

In the interim, software developers should turn their attention towards producing applications that address cognitive factors in their design. CASE (Computer-Aided Software Engineering) tools and software models with a vested interest in cognition, such as C-CAD, will enable systems to proliferate in the next ten years.

As we have shown, an increasing amount of literature surrounding cognition, language and memory now lends its support to our general hypothesis that providing a multimodal environment in which to work should lead to more efficient and complete encoding of information in LTM.

Whilst our current study pertains to long-term L2 vocabulary retention, our discussion is transferable across any area of research concerned with learning. However, we must acknowledge the influence of context and objectives upon learning strategies [Westen, 1999], and cater for these variations accordingly.

Creating user interaction models is a step in the right direction (which, *per se*, could be extracted from focus group reviews or use-diagrams); however, certain questions cannot be answered without first examining imperceptible human elements.

SECOND LANGUAGE ACQUISITION

Word retention has been related to the amount of task-induced involvement load a learner experiences during language instruction [Hulstijn & Laufer, 2001]. Here, increased load during task-involvement implies a greater level of retention. This claim is supported by the levels of processing theory [Lockhart & Craik, 1990; Craik & Lockhart, 1972], and assumes that the greater the level or depth of cognitive processing, the better the long-term retention of information.

What is critical to retention is not merely the presence or absence of semantic encoding, but also the richness with which the material is encoded [Craik & Tulving, 1975]. An obvious criticism of Involvement Load theory stems from the fact that cognitive levels are both qualitatively and quantitatively hard to define under the notion of levels of processing [Anderson, 1995], and therefore difficult to verify empirically.

In addition, the context in which learning takes place is instrumental in second language acquisition. Empirical research [Lotto & de Groot, 1998; Fitt, 1995] and psychological theories, such as the encoding specificity principal [Tulving & Thomson, 1973], demonstrate that recall ability is enhanced by contextual conditions whereby recall increases when encoding and retrieval stimuli are provided under the same series of conditions.

Contrary to our argument of increasing processing in the regions of the brain responsible for explicit-semantic memory, Lotto & de Groot [1998] found that L1-L2 translation via the use of associative pairs resulted in faster retrieval of information compared to conceptual model-based instructions. These results would indicate that exploiting implicit-associative memory is in fact more beneficial to L2 learners.

Unfortunately, as this research did not perform delayed post-test recall examinations, it failed to take into account the effects of the models upon long-term retention. We believe that these findings in favour of using L1-L2 word associative models for vocabulary acquisition as opposed to context-derived models (which we prescribe in this study) can be explained by this oversight in methodology.

Firstly, associative memory relies upon implicit memory and mostly bypasses regions of the brain responsible for the processing of explicit-semantic information. As increased processing of information has been shown to result in slower retrieval rates [Clark, 1997], the findings by Lotto & de Groot [1998] are not surprising given their experimental design. Second, activation of implicit associate memory occurs in the frontal lobes of the brain where WM takes place [Westen, 1999]. This would imply that their design exploited information that was either present in WM or easily primed by the cued stimuli.

As *networks of associations* would imply, information currently placed in WM would be more highly associated to previously organised information such as L1 knowledge, which would have been brought into WM by the provided retrieval cues inherent within the language exercise. Elaboration theory would posit that the very nature of their experiments called for the shallow processing requirements associated with associative memory and therefore has little relevance to long-term knowledge retention.

In this light, we maintain our suggestion that greater learning takes place through the use of implied meaning via context-derivative exercises. As previously discussed, the increase in cognitive processing required to assimilate the newly acquired knowledge and then to determine implied meaning should theoretically lead to deeper learning and better knowledge retention. Such findings have been submitted by Groot [2000].

SPEECH TECHNOLOGY

It is increasingly apparent that human factors are becoming the limiting factor in software design. Using multimodal design principles in speech-recognition systems is the key to future human-computer interfaces [Cohen et al, 1997].

Applications capable of continuous speech recognition and text-to-speech voice synthesis are emerging at a previously unparalleled rate as hardware and software advances render the technology more accessible.

Voice recognition has proven to be an ideal solution for eye-busy, hand-busy situations [Lai & Vergo, 1997]. However, its applicability should not be limited to novel solutions for complex problems; instead we should look to investigate its general applicability to *everyday* tasks

Amongst the speech recognition systems that have successfully been implemented, those that have implemented a multimodal design with modal compensation have enjoyed a higher degree of success and levels of user satisfaction than those that have employed a unimodal design, especially within a CALL framework [Ehsani & Knodt, 1998; Cohen et al, 1997; Cohen, 1992].

To ensure that developers maximise the benefits of speech technology, we contend that the use of a multimodal approach as a design construct is essential to the success of any user-oriented speech application.

ASR (automatic speech recognition) systems employing a multimodal design have successfully been used to decrease task performance errors, increase task performance output and significantly reduce spoken disfluencies as compared to unimodal speech-only systems [Cohen et al, 1997]. A logical use of technology, capable of such commendable results, is CALL.

A distinct advantage of natural language is that it enables the user to address areas/objects within the virtual space of the CALL application that would otherwise be unreachable with the graphic manipulation techniques favourable in present GUI designs.

In the CALL context, given the existence of intelligent language agents, spoken language would enable the learner to communicate with multiple 'virtual' speakers which is more akin to true social interaction. This is simply not feasible using current technology used in L2 acquisition tools.

Multimodal design in the case of CALL applications has the direct advantage of providing users with a freedom of expression unequalled by current standards. Key-modal interaction could be used to compensate for a lack in pronunciation proficiency. Graphic manipulation of the virtual space could aid the user to navigate around the application. This last point is essential to the success of speech technology.

For example, some natural language is inherently based and dependent upon gesture to determine meaning. Demonstrative adjectives are extremely difficult to express in natural language. During social discourse these constructs are often defined through pointing or inference of previously agreed upon information. How does a computer recognise the command, "I would like to buy *this* one?"

Voice dictation compounds this problem when having to indicate an indexed location within a screen, which from personal experience can be a challenging feat to accomplish, and is best accomplished by the aid of some pointing device such as a mouse or stylus. On the other hand, spurious utterances and hesitations are easily overcome through the use of a 'click to speech' design. This, however, is only an immediate solution to a much larger problem.

An equally important consideration when designing speech recognition applications, and one which remains largely untreated, is the impact of speech recognition on cognition.

Having to encode errors takes away from people's processing and storage capacity for normal content and leads them to commit more errors in recall. Fortunately, short-term memory is not equipped to store the irrelevancies of speech, such as hesitations and minimal utterances [Clark & Clark, 1977]. Short-term memory actually filters out this irrelevant information. This claim is supported by findings that demonstrate how these extraneous pieces of information cannot be reproduced with any significant levels of accuracy after even a short period of time [Clark & Clark, 1977].

Clark [1997] indicates that there may also be various implications for language change in SLA. As differences in language production gradually appear over generations, drastic changes may occur to a language over a period of a short time span. Whilst the call for computer-based language tools is obvious, in as much as they provide a constant reference source, voice-enabled applications will enable language instructors to faithfully reproduce a language throughout the generations.

Whilst many may think of this as suffocating a language, depriving it of its linguistic vitality and freedom to evolve, stunting the growth of a language is far more difficult than simply imposing a series of rules and regulations.

Finally, while research into speech technology continues to search for methods of rendering speech recognition more accessible to the general public, an important question arises: "How do we design for this new technology?" To date, this question has been given very little consideration [Sawaki, 2001; Hulstijn, 2000; Cohen et al, 1997; Lai & Vergo, 1997]. The present study hopes to respond to these questions and others by providing empirical evidence on the influence of multimodal design with speech recognition upon long-term L2 word retention.

As ASR and TTS capable systems continue to improve, this technology will undoubtedly find a permanent place amongst L2 learning communities, whose goals are primarily the instruction of natural communication.

LIMITATIONS

Evoking a new design principle always comes at an initial cost. There is a limited amount of empirical and theoretical evidence that supports the proposed framework. Research is severely limited in the global context, and despite best efforts, many questions central to the design framework are left unanswered.

The work presented in this paper does not claim to be unique in this respect. We submit that our hybrid model C-CAD is still in its infancy, yet believe that its first tentative steps yield sufficient promise to warrant future investment. Moreover, we call other researchers to critically appraise this cognitive-centred software design framework. As to our current discussion on L2 vocabulary retention, speech recognition and multimodal design, there are numerous limitations in the use of speech recognition with multimodal design that must be overcome before we can fully understand and profit from this area of research.

The current research does not take into account state-dependent memory, in other words, the effect of context and emotion upon encoding and retrieval ability [Westen, 1999]. As stated by Caine [1991]: "A person's physical and emotional well being are closely linked to the ability to think and to learn effectively. […] Emotions and cognition cannot be separated. Emotions can be crucial to the storage of recall and information."

Psycholinguistic questions must be addressed. Are the results transferable across age and cultural background? Are the same principles and practices alluded to in this paper applicable to grammar and sentence level production? Recent findings by Shuren et al. [1996] suggest that grammar acquisition and sentence production require greater coordination between mental processes. Laufer and Nation [1995] indicate that word difficulty plays a major role in determining vocabulary acquisition, how important is this claim within the current design framework? Does increased pseudo-social interaction with the computer lead to an increase in L2 language competency, as would be supported by Vygotsky's theory of language as a social phenomenon [1962, 1978]?

The present research is being applied to only one language, *Picard*, where virtually no SLA research has taken place [Pooley, 1996]. A longitudinal study should examine a cross-section of languages with a larger support base, which in turn will require other factors to be taken into consideration such as priming effect.

From a technological perspective, research needs examine the presentation modes of speech recognition and their respective impact on cognition. For example, at what point should the speech agents indicate that the user response is incorrect? What is the most efficient and intuitive method of modal integration? Can intelligent language agents provide mutual disambiguation and, if so, how do we strike a balance between modal control? Despite their computational and programmatic nature, accounting for human cognition is essential for their solution.

Positive results from the current study would indicate that multimodal design in CALL applications has a positive effect on semantic encoding of L2 vocabulary and its subsequent retrieval. An obvious implication of such findings would be a dramatic reduction in time for acquiring information and recalling semantic constructs (such as L2 vocabulary) from LTM. However, we stress that this should not belie the need for constant exposure to the new information [Hulstijn, forthcoming; Lotto & de Groot, 1998]. Furthermore, according to spacing theory [Dempster, 1996], exposure should occur over regular periods to enhance long-term memory retention. When all things are considered, instructors of foreign language will have a means of maximising their students' potential.[3] This principle is not only applicable to foreign language acquisition, but to any learning practice in general.

CONCLUSION

In this paper, we have shown that substantial evidence points to the benefits of the use of multimodal design in CALL applications. We have argued, based on previous empirical research and psychological theories on human cognition, that incorporating multimodal design in CALL development will lead to an increase in the cognitive processing of new information, which in turn will lead to the creation (or enhancement) of context-specific conceptual models. From this we should expect a substantive increase in long-term L2 word retention.

We have proposed a new hybrid software design model, C-CAD, to exploit the advantages of incorporating human cognition into the software development life cycle process. We submit that a cognition-centred approach to software design will lead to more intuitive and user-friendly software.

Should the results of our study uphold our primary hypothesis that multimodal design in CALL applications leads to an increase in L2 vocabulary retention, the implications for CALL, SLA, and general academic research will be far-reaching. Apart from corroborating much of the theoretical and empirical evidence available on language,

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[3] As noted by Groot [28], language learning proficiency varies from one student to another. It is assumed that more adept students will progress at a superior rate to others regardless of instruction methodology.

memory and cognition, this study will have provided key evidence as to the effect of design on *learnability*. These results will hopefully lead to further studies, which in turn will corroborate our initial findings.

As an adjunct to this article, it is our hope that preliminary results from this study will encourage other researchers to implement a design framework, such as C-CAD, within which to develop more effective and intuitive software. Whilst this article's primary focus is on SLA and long-term word retention, the principles upon which our discussion is founded are transferable across many, if not every discipline in which human-computer interaction is sought.

On a final note, it is our hope that from this study greater efforts will be taken to investigate the impact of speech technology, such as ASR and TTS, on second language acquisition. It is only a matter of time before such technology matures to the point of general applicability. Understanding its impact should therefore be a primary goal.

FUTURE RESEARCH

Research in cognition and design, especially the integration of speech technology into CALL applications, needs to continue if we are to make critical advances in human-computer interaction. Computational, linguistic and psychological issues are a few amongst many that must be addressed by future studies. We list but a few of these considerations below.

Is the perception and production of one mode altered by the presence of a second mode?

How can we best accommodate mutual disambiguation in multimodal design? To what extent can we exploit passive input, such as gesture, directed attention and lip movement [Plass, 1998]?

How do we allow for modal compensation without allowing for intrusive behaviour?

What is the effect of multimodal design on grammar acquisition and sentence level production?

It is our opinion that presentation modes deserve greater consideration during the CALL development process. Although we have centred on speech recognition and multimodal design in this paper, this is merely an instance of the design considerations that need to be addressed in the future.

REFERENCES

Abraham, R. G., & Liou, H-C. (1991). Interaction generation by three computer programs: Analysis of functions of spoken language.. In Dunkel, P. (Eds.). *Computer-assisted language learning and testing: Research issues and practice* (pp. 85-107). New York: Newbury House.

Anderson, J. R. (1995). *Learning and memory: An integrated approach*. New York: J. Wiley & Sons.

Baddeley, A. D., Lewis, V., Eldrige, M., & Thomson, N. (1984). Attention and retrieval from long-term memory. *Journal of Experimental Psychology: General, 13*, 518-540.

Bechara, A., Tranel, D., Damasio, H., Adolphs, R., Rockland, C., & Damasio, A. (1995). Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. *Science*, *29*, 1115-1118.

Braillon, J-M. (1996). La vitalité du picard rencontrée dans des pratiques pédagogiques. In J-M. Eloy (Ed.). *Évaluer la vitalité. Actes du Colloque international "Evaluer la vitalité: Des variétés régionales du domaine d'oil."* (pp. 131-141). Amiens: Centres d'Études Picardes XLVII, 1998.

Bregler, C., Konig, Y. (1994). Eigenlips for robust speech recognition. *Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing.* Adelaide: Australia.

Brown, D. (1987). *Principles of language learning and teaching* (2nd Ed.). Englewood Cliffs, NJ: Prentice-Hall.

Caine, R. N., and G. Caine (1991). *Making connections: Teaching and the human brain.* Alexandria, VA: Association for Supervision and Curriculum Development.

Chapelle, C., & Jamieson, J. (1977). Internal and external validity issues in research on CALL effectiveness. In Dunkel, P. (Eds.). *Computer-assisted language learning and testing: Research issues and practice* (pp. 37-56). New York: Newbury House.

Chen, H.-C. (1990). Lexical processing in a non-native language: Effects of language proficiency and learning strategy. *Memory and Cognition, 18*, 279-288.

Chun, D. M., & Plass, J. L. (1996). Effects of multimedia annotations on vocabulary acquisition.

Modern Language Journal, 80, 183-198.

Clark, H., & Clark, E. (1977). *Psychology and language: An introduction to psycholinguistics*. New York: Harcourt Brace Jovanovich, Inc.

Clark, R. A. J. (1997). Language acquisition and implications for language change : A computational model. *International Conference on Language Acquisition: Knowledge Representation and Processing GALA '97* [Oral Presentation].

Cohen, P. R. (1992). The role of natural language in a multimodal interface. *Proceedings of USIT'92, 1992*, 143-149.

Cohen, P. R., Johnston, M., McGee, D., Oviatt, S., Pittman, J., Smith, I., Chen, L., Clow, J. (1997). QuickSet: Multimodal interaction for distributed applications. *Proceedings of the fifth ACM international conference on multimedia* (pp 31-40). New York: ACM Press.

Collins, A., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82*, 407-328.

Craik F., Govoni R, Naveh-Benjamin M, Anderson N. D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General: 125(2)*, 159-180.

Craik, F. I. M., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General*, 104, 268-294.

Craik, F. I., & Govoni, R. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology, 125(2)*, 159-180.

Craik, F., & Lockhart, R. S. (1972). Levels of Processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11*, 671-684.

Dempster, F. N. (1996). Distributing and managing the conditions of encoding and practice. In E. L. Bjork, R. A. Bjork, (Eds.), *Memory. Handbook of perception and cognition* (2nd Ed. pp. 317-344). San Diego: Academic Press Inc.

Dunkel, P. (1991). Research on the effectiveness of computer-assisted instruction and computer-assisted language learning. In Dunkel, P. (Eds.). *Computer-assisted language learning and testing: Research issues and practice* (pp. 6-30). New York: Newbury House.

Ebbinghaus, H. (1885). *Memory*. New York: Columbia University / Dover, 1964.

Ehsani, F. & Knodt, E. (1998). Speech technology in computer-aided language learning: Strengths and limitations of a new CALL paradigm. *Language Learning & Technology, 2(1)*, 45-60.

Ellis, R. (1985). *Understanding second language acquisition*. Oxford: Oxford University Press.

Fitt, S. (1995). The pronunciation of unfamiliar native and non-native town names. *Proceedings: Eurospeech 95, 3*, 2227-30.

Gould, J. D., Boies, S. J., Levy, S., Richards, J. T., & Schoonard, J. (1987). The 1984 olympic message system: A test of behavioural principle of system design. *Communications of the ACM, 30 (9)*, 758-769.

Groot, J. M. (2000). Computer assisted second language vocabulary acquisition. *Language Learning & Technology, 4(1),* 60-81.

Hapenshi, K. (1993). Design guidelines for using speech in interactive multimedia systems. In C. Baber, & J. M. Noyes, (Eds.). *Interactive speech technology: Human factors issues in the application of speech input/output to computers*. (pp. 177-189). Bristol: Taylor & Francis.

Huckvale, M., Benoit, C., Bowerman, C., Eriksson, A., Rosner, M., Tatham, M., Williams, B. (1997). Opportunities for computer-aided instruction in phonetics and speech communication provided by the Internet. *Proceedings of Eurospeech '97. September*, 1919-1922

Hulstijn, H. J. (2000). The Use of computer technology in experimental studies of second language acquisition: A survey of some techniques and some ongoing studies. *Language Learning & Technology, 3(2),* 32-43.

Hulstijn, J. H. (forthcoming). Intentional and incidental second-language vocabulary learning: A reappraisal of elaboration, rehearsal and automaticity. In P. Robinson, (Ed.). *Cognition and second language instruction*. Cambridge: Cambridge University Press.

Hulstijn, J. H., & Laufer, B. (2001). Some empirical evidence for the involvement load hypothesis in vocabulary acquisition. *Language Learning, 51(3)*, 539-558.

Johnson, D. M. (1991). Second language and content learning with computers: Research in the role of social factors. In Dunkel, P. (Eds.). *Computer-assisted language learning and testing: Research issues and practice* (pp. 61-79). New York: Newbury House.

Kapur, S., Craik, F. I. M., Jones, C., Brown, G. M., Houle, S., & Tulving, E. (1995). Functional role of the prefrontal cortex in retrieval of memories: A PET study. *Neuroreport, 6*, 1880-1884.

Karat, C-M., Halverson, C., Horn, D., & Karat, J. (1999). Patterns of entry and correction in large vocabulary continuous speech recognition systems. *Proceedings of CHI '99, May*, 568-575.

Kolers, P. A. (1973). Remembering operations. *Memory and Cognition, 1*, 347-355.

Kolers, P. A. (1979). A pattern-analyzing basis of recognition. In L. S. Cermak & F. I. M. Craik (Eds.). *Levels of processing in human memory* (pp. 363-384). Hillsdale, NJ: Erlbaum.

Lai, J., & Vergo, J. (1997). MedSpeak: Report creation with continuous speech recognition. In *Proceedings of CHI'97* [Online], March, Atlanta. Available: http://www.acm.org/sigchi/chi97/proceedings/paper/jcl.htm [2001, October 24].

Laufer, B., & Nation, P. (1995). Vocabulary size and use: Lexical richness in L2 written production. *Applied Linguistics, 16(3),* 307-329.

Lewis, E. (1993). Interactive speech in computer-aided learning. In C. Baber, & J. M. Noyes, (Eds.). In *Interactive speech technology: Human factors issues in the application of speech input/output to computers*. (pp. 37-45). Bristol: Taylor & Francis.

Lockhart, R. S., & Craik, F. (1990). Levels of processing: A retrospective commentary on a framework for memory research. *Canadian Journal of Psychology, 44*, 87-111.

Lotto, L., & de Groot, A. M. B. (1998). Effects of learning method and wordtype on acquiring vocabulary in an unfamiliar language. *Language Learning, 48(1),* 31-69.

Madsen, H. S. (1991). Computer-adaptive testing of listening and reading comprehension: The Brigham Young University approach. In Dunkel, P. (Eds.). *Computer-assisted language learning and testing: Research issues and practice* (pp. 237-254). New York: Newbury House.

McNamara, T. F. (2000). *Language testing.* Oxford: Oxford University Press.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81-97.

Newman, W. M., & Lamming, M. G. (1998). *Interactive system design*. Essex: Addison-Wesley.

Nisbett, R. E., & Wilson, T. D. (1997). Telling more than we can know: Verbal reports on mental processes. *Psychological Review, 84*, 231-259.

Norman, D. A. (1990). *The design of everyday things*, chapter 4. New York: Doubleday.

Nyberg, L. (1998). Mapping episodic memory. *Behavioral Brain Research, 90,*107-114.

Onwuegbuzie, A. J., Bailey, P., & Daley, C. E. (2000). The validation of three scales measuring anxiety at different stages of the foreign language learning process: The input anxiety scale, the processing anxiety scale, and the output anxiety scale. *Language Learning, 50(1),* 87-117.

Oviatt, S., Cohen, P., Wu, L., Vergo, J., Duncan, L., Suhm, B., Bers, J., Holzman, T., Winograd, T., Landay, J., Larson, J., Ferro, D. (2000). Designing the user interface for multimodal speech and pen-based gesture applications: State-of-the-art systems and future research directions. *Human-Computer Interaction, 2000,* 15, 263-322.

Piper, A. (1986). Conversation and the computer: A study of the conversational spin-off generated among learners of English as a foreign language working in groups. *System, 14*, 187-198.

Plass, J. L. (1998). Design and evaluation of the user interface of foreign language multimedia software: A cognitive approach. *Language Learning & Technology, 2(1),* 35-45.

Poldrak, R. A., Desmond, J. E., Glover, G. H., & Gabrieli, J. D. E. (1998). The neural basis of visual skill learning: An fMRI study of mirror reading. *Cerebral Cortex, 8*, 1-10.

Pooley, T. (1996). Le picard dans la communcauté urbaine de Lille: Corpus, status et maintien. In J-M. Eloy (Ed.). *Évaluer la vitalité. Actes du colloque international "Evaluer la vitalité" des variétés régionales du domaine d'oil."* (pp. 73-91). Amiens: Centres d'Études Picardes XLVII, 1998.

Preece, J., Rogers, Y., Benyon, D., Holland, S., & Carey, T. (1994). *Human computer interaction*.

Chapter 2. Essex: Addison-Wesley.

Robinson, G. L. (1991). Effective feedback strategies in CALL. In Dunkel, P. (Eds.). *Computer-assisted language learning and testing: Research issues and practice* (pp. 155-167). New York: Newbury House.

Sawaki, Y. (2001). Comparability of conventional and computerized tests of reading in a second language. *Language Learning & Technology, 5 (2)*, 38-559.

Schach, S. R., (1999). *Classical and object-oriented software engineering*. (4th Ed.). Chapter 3. Singapore: McGraw-Hill International Editions.

Schneiderman, B. (2000). The limits of speech technology. In *Communications of the ACM, 43 (9)*, 63-65.

Searle, J. R. (1969). *Speech acts: An essay in the philosophy of language*. Cambridge, England: Cambridge University Press.

Shuren, J. E., Maher, L. M., Heilman, K. M. (1996). The role of visual imagery in spelling. *Brain and Language, 52*, 365-372.

Srinivasan, S., & Vergo, J. (1998). Experience in developing a framework for speech recognition applications. *Proceedings of the 1998 international conference on Software Engineering* (pp. 322-330). Washington: IEEE Computer Society.

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80*, 352-273.

Tulving, E., Kapur, S., Craik, F. I. M., Moscovitch, M., & Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emission findings. *Proceedings of the National Academy of Sciences, USA*, 91, 2016-202.

Vygotsky, L. S. (1962). *Thought andlLanguage*. Cambridge, MA: MIT Press.

Vygotsky, L.S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Wertsch, J.V. (1985). *Culture, communication, and cognition: Vygotskian perspectives*. Cambridge University Press.

Westen, D. (1999). *Psychology: Mind, brain and culture.* (2nd ed.). Chapter 6. New York: John Wiley & Sons

Westen, D. (1999). *Psychology: Mind, brain and culture.* (2nd ed.). Chapter 13. New York: John Wiley & Sons.

Wheeler, M. A., Stuss, D. T., & Tulving, E. (1995). Frontal lobe damage produces episodic memory impairment. *Journal of the International Neuropsychological Society, 1,* 525-533.

Wixted, J., & Ebbesen, E. (1991). On the form of forgetting. *Psychological Science, 2*, 409-415.

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