THE ROLE OF ATTENTION IN THE DESIGN OF LEARNING MANAGEMENT SYSTEMS

Claudia Roda
American University of Paris – France

Thierry Nabeth
CALT INSEAD - France

ABSTRACT

Modern learning environments would greatly benefit from a better management of two apparently conflicting goals. On the one hand, in order to support autonomous, self paced, and discovery oriented learning, learners must be offered access to a large amount of information and tools. On the other hand the quantity and variety of the information and tools provided should not overwhelm learners who should instead be guided in the access, use, experimentation, and synthesis of the available resources.
We propose that a shift of focus from *information presentation* to *attention guidance* in system design may allow reconciling the conflict between increased informational need and the limited human cognitive capabilities. On the basis of findings in cognitive psychology and pedagogy, we present some of the issues that should be taken into consideration for the design of systems capable of such guidance and we propose how these may be integrated in the architecture of an *attention aware learning management system*.

KEYWORDS

Attention, learning management systems, information overload.

1. INTRODUCTION

As more teachers, both in academia and in industry, embrace teaching philosophies aiming at giving learners a more fulfilling experience than simple lecture style teaching, many researchers study how information technology may support these new pedagogical styles, and several tools are being developed to help teachers in their efforts. These tools include: specialised software presenting instructional material addressing a specific subject, simulation software allowing learners to experiment with modelling real world situations, educational games, and Learning Management Systems (LMSs). In this paper we concentrate on the latter type of systems which allow teachers to distribute content and track its use by students, to manage communication within the community, to create and manage grade books, class lists, course calendars, surveys, and exams.

Supporting dynamic, contextualised, student centred, learning experiences normally involves making available to students, teachers, and surrounding communities a wealth of tools, and information that is often several orders of magnitude larger than what is available in classic, lecture style, approaches. Furthermore several modern teaching methodologies address real-world tasks as part of the learning experience. Some authors have already noted how "such tasks are typically associated with a very high cognitive load, which makes it more important than ever to take the limited human-processing capacity into account." (van Merrienboer et al. 2003, p.11). This richness of information and tools, whilst having the advantage of creating a much more challenging and stimulating environment, often results in the well-known problem of information overload. Information overload has many undesired consequences (Heylighen 2004). This is especially the case in learning environments where creating and maintaining focus is often more fruitful than quickly shifting attention from one subject to another, or one activity to another.

We believe that the success of future LMSs will depend on their ability to support human attentional processes (i.e. the processes that control access to human limited processing resources) in order to supply the necessary tools and information whilst also focussing learner's attention on the appropriate subjects. Systems capable of supporting human attentional processes, *attention aware systems* (Roda and Thomas 2006b), have recently been the subject of several research efforts (Horvitz et al. 2003; Vertegaal 2003; Roda and Thomas 2006a). However the application of such systems to learning management environments has rarely been addressed. This paper contributes to the definition of the most significant issues that should be taken into consideration for the creation of *attention aware learning management systems*.

2. ATTENTION IN NEW LEARNING ENVIRONMENTS

2.1 Towards attention aware learning environments

There seem to be a great misunderstanding underlying the design of some of the current IT based learning environments aimed at supporting learning modes different from classic lecture style mode. This misunderstanding appears to be a legacy of the classic lecture style teaching. The lecture style mode is based on a "transfer" of information or knowledge from the teacher to the student. In these settings the most pressing issue is to present learners with information. The focus is on *information presentation*. Emphasis is on teacher's selection of the information to be presented, and mode of presentation. This selection happens at "configuration" time when the teacher uses the LMS tool to prepare his or her lecture.

It appears that the same focus has been maintained in the design of learning environments that are instead designed to support different types of learning such as experiential, project-based, and contextual. However, learning modes such as the ones just mentioned assume that learners can somehow shape their own learning experience (Papert and Harel 1991). Different people may choose to access different information and tools at different times and, in general, it is difficult to foresee *who will need what, when*. The solution proposed by many instructors and learning systems that have maintained the *information presentation* focus, is to provide as much access as possible to information and tools so that students can choose those best suited to their needs. This often results in overwhelming environments where learners have difficulties finding their way, selecting the appropriate course of action, and generally focussing their attention.

Consequently we have tried to address the questions of how to make knowledge available to learners without drowning them in an ocean of information, and of how to give learners more autonomy without leaving them unguided and incapable of formulating problems, identifying important issues, and recognising achievements. Giving access to relevant resources must be accompanied by minimising distraction factors. The teacher's role, that instructional software should support, is that of a guide capable of concentrating students' attention on the most relevant items. The focus of system design should then shift from *information presentation*, to *attention guidance*.

2.2 What is attention?

The most prominent theories in cognitive psychology see attention as the set of processes enabling and guiding the selection of incoming perceptual information in order to limit the external stimuli processed by our bounded cognitive system and to avoid overloading it (Posner 1982; Lavie and Tsal 1994; Chun and Wolfe 2001; Driver 2001). Attention can either be controlled voluntarily by the subject, or it can be captured by some external event. The former type of control mechanism is referred to as endogenous, or top-down, goal driven attention (Posner 1980; Yantis 1998; Arvidson 2003). The latter type of mechanism is referred to as exogenous, bottom-up, or stimulus-driven and it may have different degrees of power so that certain stimuli become basically impossible to ignore (e.g. sudden luminance changes), whilst others are more controlled by volition. Chun and Wolfe (2001, p.279) explain that "endogenous attention is voluntary, effortful, and has a slow (sustained) time course; […] exogenous attention draws attention automatically and has a rapid, transient time course". However, exogenous and endogenous mechanisms are not independent but interact constantly so that the endogenous mechanism in place (e.g. what one is looking for in a visual field) may determine whether one will automatically be able to ignore certain exogenous stimuli.

2.3 Supporting attentional processes in learning environments.

Because attention is controlled both top-down and bottom-up, there are two ways in which we can direct students' attention: working on learners' motivation, and working on the type of stimuli. This implies that the system should be able to reason about both reactive processes controlling attention, and deliberative/motivational processes controlling attention, as well as about their interaction. For example, the system should be designed to use reactive processes (e.g. attention shift caused by a visual stimulus) in order to trigger deliberative processes (e.g. the student's reflection on a particular state of affairs). On the other hand, such system should also be aware of how reactive processes are pruned by deliberative process (e.g. certain external stimuli are not noticed because one's attention is focused elsewhere), or how the presentation of new stimuli may generate interruptions or phenomena of split attention (i.e. attention drawn by more than one target) in the current activity.

We propose to augment LMSs with an *attention management component* capable of the reasoning described above, and ultimately capable of deciding, at run time, which information, at what time, and in which format, is best suited for presentation to the learner in order to minimise cognitive load.

Section 3 introduces relevant theories of attention in psychology and pedagogy; based on these theories, section 4 discusses how such *attention management component* may be designed.

3. HOW DO ATTENTIONAL PROCESSES WORK?

3.1 Stimuli selection

The question of how exactly the selection of exogenous stimuli may take place has guided a large portion of the cognitive psychology debate on attention processes. Early theories on attention (Broadbent 1958) hypothesised a two stage processing of external stimuli. First a parallel preattentive process would take place filtering out all the non-relevant (unattended) stimuli on the basis of simple physical properties of incoming stimuli. Second, a serial, attentive stage capable of only limited processing would encode more abstract properties of the attended stimuli. Later theories (Deutsch and Deutsch 1963; Norman 1969; Duncan 1980) proposed that all stimuli are analysed, but only pertinent stimuli are selected for awareness and memorisation. However, the theories that currently seem to gather most support propose that although not all the stimuli are analysed, non attended stimuli are not completely filtered out either, rather their contribution to the attentive stage is somehow limited (Treisman 1960; Neisser 1967; Treisman 1969; Pashler 1998) and that stimuli impact depends upon their relevance to the environment or personal experience (Treisman 1960).

Many current learning environments emphasise *information access*, for example by providing students with links to a wealth of information. However, the bottom-up selection processes involved in choosing sensory input implies that displaying information not immediately relevant may reduce focus on, or increase the cognitive load needed for, focussing on more relevant information. This issue is also addressed by Cognitive Load Theory (Sweller 1988) and empirically confirmed by some experiments, in explanatory settings, where the presentation of "embellished" information resulted in "lower" learning when compared to the presentation of only core information (Mayer and Moreno 2002).

3.2 Relevance evaluation

The question arises of what information (about the environment and personal experience) should be used for the evaluation of stimuli relevance. Research on the influence of top-down processes on the stimuli selection process can help in answering this question. Amongst the wealth of theories modelling these processes (see for example (Hewett 2000; Kieras et al. 2000; Kruschke 2001; Rubinstein et al. 2001; ACT-R Research Group 2002 - 2005; Kruschke 2003)), Grossberg's Adaptive Resonance Theory (Grossberg 1976a; Grossberg 1976b; Grossberg 1999) addresses in an elegant manner the above question whilst explaining the role of attentional processes in learning. Grossberg proposes that learning involves the creation of a set of expectations with respect to external stimuli. These expectations allow us to focus on the expected data when it becomes available whilst filtering out other sensory signals. It is the *resonance* (the input activating the expectation which in turn selects the input) between expectation and received input that brings certain stimuli to the conscious state and ultimately generates learning.

3.3 Interference

Information relevance and availability however, don't seem to be the only mechanisms guiding human selection of input stimuli. This is demonstrated by the fact that sometimes we seem to be unable to disregard irrelevant stimuli, and other times we seem to miss noticing something that is obviously present in our perceptual field. Many authors have addressed these characteristics of attention. For example, Lavie and Tsal propose that "irrelevant information will be excluded from processing only if the prioritised relevant processing exhausts all of the available capacity" (Lavie and Tsal 1994, p.185). Thus, we cannot ignore external stimuli unless we have reached a minimal perceptual load (Lavie 2000). Other studies in *change blindness*, address the "failure to see large changes that normally would be noticed easily" (Simons and Rensink 2005, p.16), see also (Rensink 2000). Furthermore, distractors may delay attentional processes especially when the distractors are temporally near and conceptually related to the target stimulus. These delays are called *interference effects* (Rafal and Henik 1994, p.31). Classic examples of interference are *negative priming* (Tipper 1985) and the *Stroop effect* (Stroop 1935). *Negative priming* is the effect by which "it is more difficult to select a stimulus, belonging to a given category, for the control of action, if that same category of object was actively ignored on the preceding trial" (Allport 1989, p.659). The *Stroop effect* is a visual inhibition that occurs when a presented word indicates a different colour than the font type is. Similar interferences are explained by (Kruschke 2001; Kruschke 2003) in terms of *learned attention* and *learned inattention* so that in order to reduce errors we actually learn how to pay attention to certain cues rather than others and once we have learned to ignore certain cues it is more difficult to notice those cues when they become relevant.

3.4 Motivation

Whilst explicit, conscious motivation obviously influences attentional choices, it has been demonstrated - for a review of the literature see (Klinger 1996) - that motivation influences attention also at the unconscious level by generating a bias towards stimuli that are directly relevant for the current goal pursuit, task performed, or that are related to the *current concerns* of a person. Where *current concern* "refers to the state of an individual between two time points, the one of becoming committed to pursuing a particular goal and the other of either attaining the goal or giving up the pursuit" (Klinger and Cox 2004, p.9). The effects of current concerns on cognition are "nonconscious and automatic rather than attributable to a conscious process" and "goal-related cues, even nonconscious ones, also appear to exert automatic effects on goal-directed actions."(Klinger and Cox 2004, p.15). It appears that, at the motivational / affective level, a *valence* (negative, positive, or neutral) is associated to stimuli. This valence may be mediated by the current goal or task, i.e. its value is relative to the contribution to the current goal. Attention is then directed to information that has positive or negative valence (see (Rothermund et al. 2001) for a summary of experiments conducted on this issue). Research on this aspect of motivation is based on the premise that stimulus valence is both essential for regulating action and it can be easily identified without conscious processing. Goals are also considered has having a valence, positive goals are those aimed at attaining something, negative goals are those aimed at avoiding something (Klinger and Cox 2004). Interestingly, attentional bias toward valent stimuli appears to be influenced by current goal and action orientations so that stimuli of valence opposite to the goal's valence attract attention more that stimuli with the same valence (Rothermund et al. 2001; Rothermund 2003b). When a goal is adopted attention is automatically (unconsciously) attracted by goal-related (or task-related) stimuli (Klinger 1996; Moskowitz 2002; Klinger and Cox 2004). Current theories mostly agree that when a goal is attained (or a task completed) automatic vigilance is terminated. Furthermore some recent experiments indicate that task-related information is actively inhibited after the successful execution or cancellation of a goal (or intention) (Marsh et al. 1999; Rothermund 2003a) and that a goal-related attentional set remains active even in the face of failure, e.g. when one finds out that the goal cannot be achieved (this latter effect is called *perseverance hypothesis*) (Rothermund 2003a).

3.5 Emotions

Research results in behaviour processing (see (Compton 2003) for a review) highlights the fact that fine tuning of the interface with respect to attentional processes would also need to take into consideration other factors such as the students' emotions, or moods. Gasper & Clore (2002), for example, report of two experiments supporting the hypothesis that "affective cues may be experienced as task-relevant information, which then influences global versus local attention" (p. 34). The relevance of emotional processes both in designing systems capable of interacting effectively with humans, or of simulating human behaviours, is indeed been recognised by a growing community of researchers (Picard 1997; Breazeal 2002; Norman et al. 2003; Trappl et al. 2003).

3.6 Minimising cognitive load with respect to specific tasks

Finally we briefly turn to the problem of minimising cognitive load in task execution. Most research, mainly based on Cognitive Load Theory, shows that the fundamental bottleneck in task execution is human's limited working memory. Amongst the approaches proposed to deal with this limitation a promising one is taken by Van Merrienboer et. al. (2003) who propose that task support is constituted of either *supportive information*, or *procedural information*. *Supportive information* is related to the knowledge necessary for problem solving and reasoning, it can be considered the theory of the task, and it describes mental models and cognitive strategies. The authors argue that this type of information is "best presented explicitly just before the task class for which it is relevant. […] it is kept available for the learners while working on the learning tasks" (ibid, p.10). *Procedural information* is related to consistent task components or recurrent task aspects that are performed as routines by experts, and has normally a low level of complexity. Procedural information should be integrated in the task environment and presented when the learner needs it in order to avoid phenomena of split attention that would be generated by the need of integrating, during task performance, information that is supplied separately.

4. A PROPOSED ARCHITECTURE FOR ATTENTION AWARE LMS

In section 2.3 we have discussed the need and the value to augment LMSs with an *attention management component* capable of dynamically deciding which information, at what time, and in which format is best suited for presentation to the learner. In this section we present the architecture of such an *attention aware LMS* built on the basis of design principles emerging from the theories presented in sections 3.

In section 3.1 we have seen that stimuli impact depends upon their relevance in the current environment or with respect to personal experience. LMSs necessarily have limited information about the student's current environment and personal experience (just as teachers do) however this information should be used both to assess what is most relevant for the student at a given time and to evaluate how likely it is that the presented information will be noticed by the student. We capture this intuition in a first sketch (figure 1) of the structure of an *attention aware learning management system.* The attention management component should rely on both a model of the user and on meta-level information associated to content allowing the evaluation of its relevance with respect to the user model. In this section, we will use the theoretical results presented early to better define this first sketch. The results of this refinement process are depicted in figure 2.

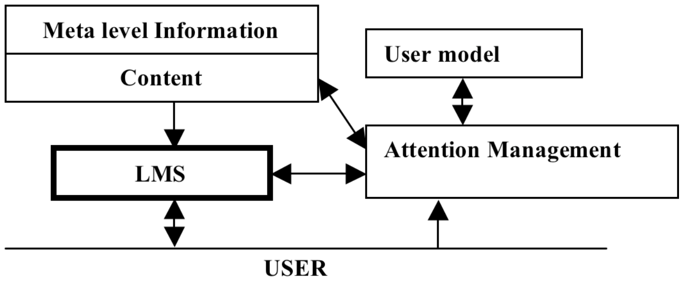

Figure 1 – A schematic view of an attention aware learning management system

In our architecture, both information about the user and about the content are partially supplied by users (teachers and learners) and partially generated by the system. Users provide content along with the information necessary for its selection by the system at run time (meta-level information); they are also able to access and update information in the user model.

The attention management component monitors the user's action and the environment and has some capabilities for tracking learner's moods/emotion as suggested by the theories mentioned in section 3.5. These monitoring functions provide the information necessary to update the meta-level information and the user model as described below. The attention management component can reason about motivational and stimulus driven processes controlling attention in order to provide suggestions to the LMS on the content to display, the timing of display, as well as the format. See attention management box in figure 2.

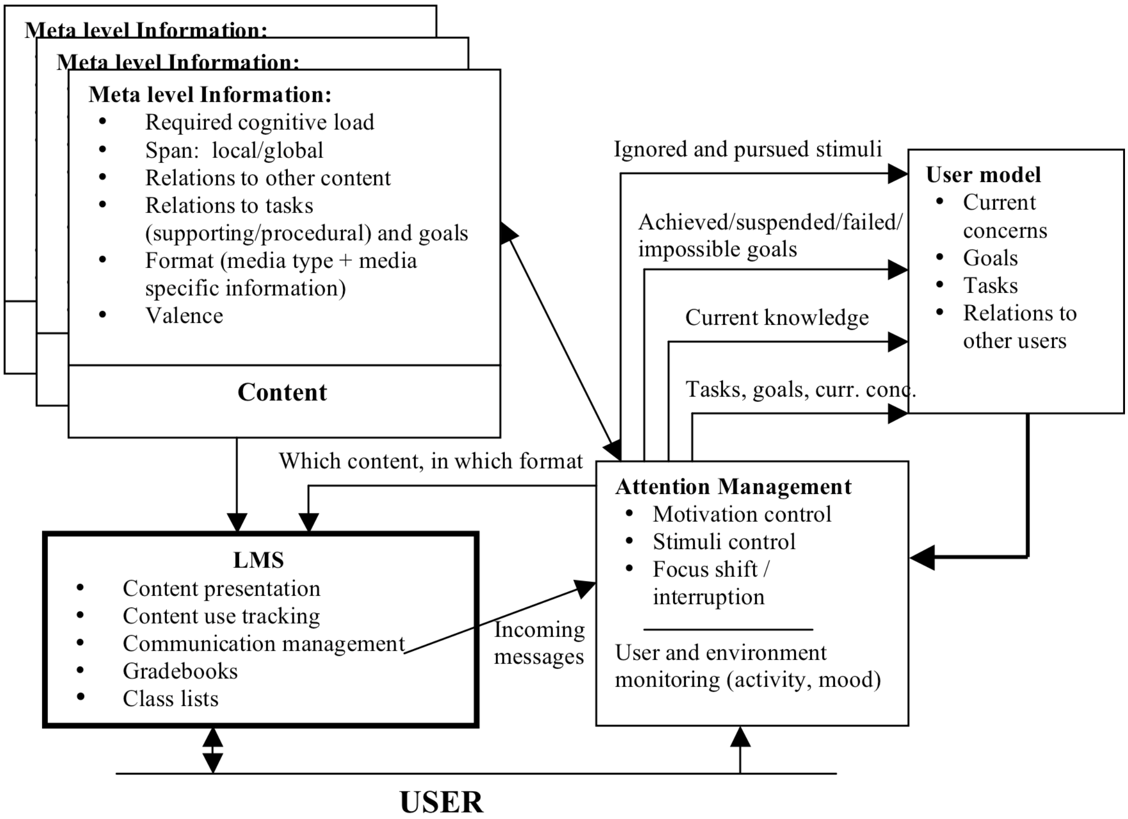

Figure 2 – Some essential informational elements of an *attention aware learning management system*

We interpret Adaptive Resonance Theory (section 3.2) as highlighting the importance of previous students' knowledge in learning environments, in particular, the necessity to link new stimuli to previous ones. For this reason, in figure 2, the attention management component maintains, in the user model, information about the learner's current knowledge (what has been presented so far). Relation between each piece of content and other content, tasks, and goals is maintained in the content's meta-level information. This meta-level information includes information allowing the system to discriminate between different types of "information utility" (e.g. supportive, procedural) with respect to tasks (see section 3.6).

Negative priming and learned inattention effects (section 3.3) may explain why students may fail to notice frequently displayed, normally irrelevant, elements of the interface when they become relevant. For example, focussing on a menu item that has always been present but has just become relevant requires a larger effort than what it would have required if that item had just appeared at the appropriate time. In figure 2, the attention management component keeps information about ignored and pursued stimuli that may be used to prevent (or provoke) interference effects.

Whilst attention allocation to stimuli related to active goals and *current concerns* is almost unavoidable, it may only take place at unconscious / affective level (section 3.4). However it is possible to control the level

of attention to certain stimuli by presenting them with valences that are either congruous or incongruous with the goal valence. In the context of positive (*approach*) goals, such as "Propose short-path solutions to the search problem P", or "Please complete this assignment", students' attention will be biased towards stimuli of negative valence, such as "you are not allowed to go through state S1 more than once", or "the assignment will not be accepted after next Tuesday". In the context of negative (*avoidance*) goals, such as "Avoid long-path solutions to the search problem P", or "Please don't forget to complete this assignment" students' attention will be biased towards stimuli of positive valence such as "you should go through state S1 at most once", or "the assignment is due by next Tuesday at the latest". Further studies on message valence, on how valence may be evaluated by different subjects, and on the reaction to valent messages in the context of certain tasks, goals, and *current concerns*, may be very beneficial for the design of interfaces capable of fine tuning messages to attract the desired level of students' attention. To capture this intuition we include a *valence* indicator in the content's meta-level information of figure 2.
Figure 2, detailing figure 1, captures essential elements of an *attention aware LMS* as discussed in this paper.

5. CONCLUSIONS

Whilst we have strived to give a fairly balanced overview of the matters involved in the design of *attention aware learning management systems*, we have necessarily excluded or only mentioned some important subjects. These include all issues related to collaborative environments, management of interruptions, timing of interventions, and methodologies for monitoring the user activity and the environment. We hope however that the many issues that we have presented and organised within our tentative architecture form a good basis to stimulate further research by computer scientist, pedagogues, and psychologists, in the design of *attention aware learning management systems*.

REFERENCES

ACT-R Research Group, 2002 - 2005. ACT-R, Department of Psychology, Carnegie Mellon University.

Allport, A., 1989. Visual attention. *Foundations of Cognitive Science*. M. Posner. Cambridge, MA, MIT Press**:** 631–681.

Arvidson, P. S., 2003. A lexicon of attention: from cognitive science to phenomenology. *Phenomenology and the Cognitive Sciences* 2(2): 99-132.

Breazeal, C., 2002. *Designing Sociable Robots*. MIT Press, Cambridge, MA

Broadbent, D. E., 1958. *Perception and communication*. Pergamon Press, London

Chun, M. M. and J. Wolfe, 2001. Visual Attention. *Blackwell's Handbook of Perception*. E. B. Goldstein. Oxford, UK, Blackwell**:** 272-310.

Compton, R. J., 2003. The Interface Between Emotion and Attention: A Review of Evidence From Psychology and Neuroscience. *Behavioral and Cognitive Neuroscience Reviews* 2(2): 115-129.

Deutsch, J. and D. Deutsch, 1963. Attention: Some theoretical considerations. *Psychological Review* 70: 80-90.

Driver, J., 2001. A selective review of selective attention research from the past century. *British Journal of Psychology* 92: 53-78.

Duncan, J., 1980. The locus of interference in the perception of simultaneous stimuli. *Psychological Review* 87(272-300).

Gasper, K. and G. L. Clore, 2002. Attending to the Big Picture: Mood and Global Versus Local Processing of Visual Information. *Psychological Science* 13(1): 34-40.

Grossberg, S., 1976a. Adaptive pattern classification and universal recoding. I. Parallel development and coding of neural feature detectors. *Biological Cybernetics* 23: 121–134.

Grossberg, S., 1976b. Adaptive pattern classification and universal recoding. II. Feedback, expectation, olfaction, and illusions. *Biological Cybernetics* 23: 187–202.

Grossberg, S., 1999. The Link between Brain Learning, Attention, and Consciousness. *Consciousness and Cognition* 8(1): 1-44.

Hewett, M., 2000. Computational Perceptual Attention. *Department of Computer Sciences*. Austin texas, University of Texas at Austin.

Heylighen, F., 2004. Complexity and Information Overload in Society: why increasing efficiency leads to decreasing control. *Technological Forecasting and Social Change* [submitted](available at: http://pcp.vub.ac.be/Papers/PapersFH2.html).

Horvitz, E., et al., 2003. Models of attention in computing and communication: from principles to applications. *Communications of the ACM* 46(3): 52-59.

Kieras, D. E., et al., 2000. Modern Computational Perspectives on Executive Mental Processes and Cognitive Control: Where to from Here? *Control of Cognitive Processes: Attention and Performance XVIII*. S. Monsell and J. Driver. Cambridge, MA, M.I.T. Press**:** 681-712.

Klinger, E., 1996. Emotional influences on cognitive processing, with implications for theories of both. *The psychology of action: Linking cognition and motivation to behavior*. P. M. Gollwitzer and J. A. Bargh. New York, Guilford Press**:** 168–189.

Klinger, E. and W. M. Cox, 2004. Motivation and the Theory of Current Concerns. *Handbook of Motivational Counseling*. W. M. Cox and E. Klinger, John Wiley & Sons**:** 3 - 27.

Kruschke, J. K., 2001. Toward a Unified Model of Attention in Associative Learning. *Journal of Mathematical Psychology* 45(6): 812-863.

Kruschke, J. K., 2003. Attention in learning. *Current Directions Psychological Science* 12: 171-175.

Lavie, N., 2000. Selective attention and cognitive control: dissociating attentional functions through different types of loads. *Attention and Performance, Vol XVIII, Control of cognitive processes*. S. Monsell and J. Driver. Cambridge, MA, MIT Press**:** 175-197.

Lavie, N. and Y. Tsal, 1994. Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & Psychophysics* 56(2): 183–197.

Marsh, R. L., et al., 1999. The activation of un-related and canceled intentions. *Memory & Cognition* 27(2): 320-327.

Mayer, R. E. and R. Moreno, 2002. Aids to computer-based multimedia learning. *Learning and Instruction* 12(1): 107-119.

Moskowitz, G. B., 2002. Preconscious effects of temporary goals on attention. *Journal of Experimental Social Psychology* 38(4): 397-404.

Neisser, U., 1967. *Cognitive Psychology*. Appleton-Century-Croft, New York

Norman, D., 1969. *Memory and attention: An introduction to human information processing*. Wiley, New York

Norman, D., et al., 2003. Affect and machine design: Lessons for the development of autonomous machines. *IBM system Journal* 42(1): 38-44.

Papert, S. and I. Harel, 1991. Situating Constructionism - Chapter 1. *Constructionism*. S. Papert and I. Harel, Ablex Publishing Corporation.

Pashler, H., 1998. *The Psychology of Attention*. MIT Press, Cambridge, MA

Picard, R. W., 1997. *Affective Computing*. MIT Press, Cambridge, MA

Posner, M., 1980. Orienting of attention. *Quarterly Journal of Experimental Psychology* 32: 3-25.

Posner, M., 1982. Cumulative development of attention theory. *American Psychologist* 37: 168-179.

Rafal, R. and A. Henik, 1994. The neurobiology of inhibition: integrating controlled and automatic processes. *Inhibitory Processes in Attention, Memory, and Language*. D. Dagenbach and T. Carr. New York, Academic Press.

Rensink, R. A., 2000. Seeing, sensing, and scrutinizing. *Vision Research* 40(10-12): 1469-1487.

Roda, C. and J. Thomas, Eds. 2006a. *Attention Aware Systems. Special Issue of the journal Computers in Human Beaviour*, Elsevier.

Roda, C. and J. Thomas, 2006b. Attention Aware Systems: Theories, Applications, and Research Agenda. *Computers in Human Behavior* Forthcoming.

Rothermund, K., 2003a. Automatic vigilance for task-related information: Perseverance after failure and inhibition after success. *Memory & Cognition* 31: 343-352.

Rothermund, K., 2003b. Motivation and attention: Incongruent effects of feedback on the processing of valence. *Emotion* 3: 223-238.

Rothermund, K., et al., 2001. Automatic attention to stimuli signalling chances and dangers: Moderating effects of positive and negative goal and action contexts. *Cognition and Emotion* 15: 231-248.

Rubinstein, J. S., et al., 2001. Executive Control of Cognitive Processes in Task Switching. *Journal of Experimental Psychology: Human Perception and Performance* 27(4): 763-797.

Simons, D. J. and R. A. Rensink, 2005. Change blindness: past, present, and future. *Trends in Cognitive Sciences* 9(1): 16-20.

Stroop, J., 1935. Studies of interference in serial verbal reactions. *Journal of experimental psychology* 18: 643–662.

Sweller, J., 1988. Cognitive load during problem solving: effects on learning. *Cognitive Science* 12: 257–285.

Tipper, S. P., 1985. The negative priming effect: Inhibitory effects of ignored primes. *Quarterly Journal of Experimental Psychology* 37A: 571-590.

Trappl, R., et al., 2003. *Emotions in Humans and Artifacts*. MIT Press, Cambridge, MA

Treisman, A., 1960. Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology* 12: 242 - 248.

Treisman, A., 1969. Strategies and models of selective attention. *Psychological Review* 76: 282 - 299.

van Merrienboer, J. J. G., et al., 2003. Taking the load of a learners' mind: Instructional design for complex learning. *Educational Psychologist* 38(1): 5-13.

Vertegaal, R., 2003. Attentive user interfaces. *Communications of the ACM* 46(3): 30-33.

Yantis, S., 1998. Control of Visual Attention. *Attention*. H. Pashler. London, UK, University College London Press**:** 223-256.