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New Forms of Deep Learning on the Web: Meeting the Challenge of Cognitive Load in Conditions of Unfettered Exploration in Online Multimedia Environments

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ABSTRACT

We claim that the Web has the potential to be a quintessential multimedia environment for complex learning, particularly in ill-structured domains. This chapter explores the cognitive load considerations associated with several aspects of deep and extended learning on the Web. We also propose the need for a reconceptualization of Cognitive Load Theory for comprehension and learning in more ill-structured conceptual arenas. This reconceptualization emphasizes the need for learning approaches that promote flexible knowledge assembly through processes of organic, reciprocal, and deep Web learning.

INTRODUCTION

The Web has the potential to become a quintessential multimedia learning environment. Both formal and informal learners are increasingly turning to the search engine as their primary source of information. For example, college students regularly use the Internet and commercial search engines (e.g., Google) before, or in lieu of, local library resources (Griffiths & Brophy, 2005; Jones, 2002; Thompson, 2003; Van Scoyoc, 2006). At the same time, the content provided to them on the Web is presented in multimedia form, often comprising various combinations of text, data, pictures, animation, audio, and video, of differing levels of interactivity. These myriad forms of information all battle for learner attention and consideration.

The second author argued that this migration away from traditional information resources to Web mediated multimedia learning environments is ushering in a revolution in thought, a New Gutenberg Revolution (2006a, b, c, d, e). He outlined how, given the dramatic increases in the speed with which information can be accessed, the increasing well directedness of search (due to more advanced search algorithms, data organization, and searcher skill), and the *de facto* assumption of "ambient findability" (Morville, 2005), the Web is becoming a more fertile knowledge landscape than man has ever known. Consequently, the Web is particularly well suited to support *deep* learning for subjects and concepts that are complex and ill-structured; the kind that we seem to be finding more and more of in the world everyday. These domains of knowledge demonstrate an *irregularity* of conceptual application across instances and context that is inherent to ill-structuredness (for discussion of the special qualities of learning in ill-structured domains, see Spiro & DeSchryver, in press; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987; Spiro, Feltovich & Coulson, 1996).

In order to harvest information from this landscape in the most effective and meaningful ways, learners will need to explore the Web with a Post-Gutenberg Mind. This involves searching with *advanced Web exploration* techniques and an *opening mindset* that together result in advanced knowledge acquisition that goes well beyond the cursory and fact based searches most common to learning on the Web (Kuiper, Volman & Terwl, 2005). The knowledge structures acquired by a Post-Gutenberg Mind will be tailored assemblages that are contextualized, interconnected, and flexible, enabling the everyday creativity necessary to succeed in a world increasingly driven by complex and rapidly changing information.

Sounds great, doesn't it? Well, as it turns out, not everyone is prepared to use the Web to learn like this right now. In fact, we do not really know precisely how deep learning on the Web occurs. As such, it is imperative that we begin to thoroughly examine the phenomenon. We need to better understand the specific ways that Post-Gutenberg learning will manifest itself. What specific affordances and aspects will enable deep Web learning of ill-structured concepts? How will they differ from the characteristics of traditional learning? How will we best prepare learners to maximize the benefits of deep learning on the Web? What will be the cognitive load considerations for learning that is of such depth and complexity?

With these questions in mind, we recently embarked on an inquiry to investigate the emergent aspects of Post-Gutenberg learning for an advanced Web learner in an ill-structured domain. In this study, we documented the decision-making, knowledge construction, and general learning reflections of an advanced Web searcher who examined climate change through deep and extended Web learning. The data were collected from a baseline mind-map of existing knowledge, extensive notes taken by the learner during each session, the parallel use of Clipmarks (an online tool that allows for portions of web resources to be saved, tagged, annotated, updated, and retrieved by topic or Boolean search), and corresponding updates to the mind-map. A detailed analysis of the data collected from this study has provided a better picture of what Post-Gutenberg learning may look like. And, while we do not claim any generalizability from the results of this demonstration case study (i.e., we sought to demonstrate what *is possible* not *what is*), several interesting phenomena emerged that are worthy of continued scholarly examination. For a more detailed presentation of the theoretical implications of our study, see Spiro and DeSchryver (in preparation); for a more detailed accounting of a full list of deep Web learning aspects and their derivation, see DeSchryver and Spiro (in preparation).

One of the primary considerations that surfaced was whether this form of advanced knowledge acquisition would be, in general, too challenging for the learner. Cognitive Load Theory has provided an excellent framework with which to address these questions (e.g., see Sweller, van Merrienboer & Paas, 1998; van Merrienboer & Sweller, 2005). Therefore, this chapter focuses on the cognitive load implications of deep Web learning in ill-structured domains that were identified during our investigation. First, we present an overview of deep Web learning. Second, we review the basic assumptions of Cognitive Load Theory and suggest the need to reconceptualize cognitive load as it relates to the goals of learning in ill-structured domains and the skills needed for the requisite flexible knowledge acquisition. Finally, we discuss the cognitive load considerations for specific aspects of deep learning in ill-structured domains on the Web, the adjunct online tools that support them, and related motivational developments.

DEEP WEB LEARNING AND THE NEW GUTENBERG REVOLUTION

Post-Gutenberg learning holds the promise for increasingly complex, but cognitively manageable knowledge acquisition, through learning and instruction that better fits the contours of the world and knowledge about that world. Among other things, it may provide answers to many of the greatest challenges to learning complex and ill-structured topics by supporting the development of the type of adaptive knowledge application that is increasingly important in the world today.

The foundation of Post-Gutenberg learning is the dramatically increasing high speed of connection and access to effectively unlimited Web resources. The former has resulted from technical advancements in hardware and software (e.g., search engine and data-mining algorithms that result in more precise results); enhanced techniques for information organization, such as tagging *en masse*; and, increased integration that advanced Web learners are demonstrating for information search, access, and evaluation (DeSchryver & Spiro, in preparation; Tremayne & Dunwoody, 2001). The seemingly unlimited nature of information available on the Web is described by Morville's (2005) notion of ambient findability, or the crossroads of ubiquitous computing and the Web, in which we can find anyone or anything from anywhere at anytime. This breadth and depth of knowledge provides a multiplicity of perspective, context, interconnectedness, and points of entry that are essential to learning complex, ill-structured concepts.

Most current Web-based learning is rather cursory and fact based (Kuiper, Volman, & Terwel, 2005), therefore new skills and approaches are needed to in order for Post-Gutenberg learning to develop. Foremost among these are the ability to search using *advanced Web exploration* techniques and with an *opening mindset* that promotes more wide ranging searches that go well beyond finding facts or "answers" by using just simple Google results or embedded hyperlinks in one's search. These wide ranging searches unfold using learner-initiated, complex, reciprocally adaptive (LICRA) techniques that capitalize on the Web's affordances for deep learning by permitting maximally unfettered and externally oriented nonlinear traversals of knowledge spaces. We use "externally oriented" in the sense that the learner's next steps can be strongly influenced by the content that is encountered in Web explorations, rather than operating with more internally driven or "top-down" expectations and learner guidance, such as that provided by embedded and precompiled hyperlinks or simple sequential review of Google result lists. The learner creates their own search phrases based on information they encounter on the Web, either through employing specific ideas from the current page as new search phrases, or by conceptualizing novel search phrases based on recent activity, past experience, and/or the related momentum Web learning affords. These techniques result in learner controlled non-linear movement through the conceptual landscape, where the learner creates "undefined" connections between resources. In our recent investigation, this LICRA type searching led to several more conceptual breakthroughs than did the use of existing embedded hyperlinks (DeSchryver & Spiro, in preparation).

While performing these searches, learners much be prepared for discovery, complexity, change, and creativity (Spiro, 2006a) and see the Web as *open* to their exploration. When reflected in LICRA searches, openness allows the learners to see the key phrases or ideas in the current document (text, animation, audio, or video) that merit a new branching inquiry. An opening mindset also includes being open to using the Web for more than "basic" Web searches. At Google alone, searches through images, videos, blogs, scholarly materials, books, and news are separately available. Searching with these individual engines provides several unique knowledge landscapes, variant representations, and differing perspectives based on the identical search phrase. Finally, an open mindset is essential to taking advantage of the myriad opportunities for unexpected and *serendipitous* learning on the Web.

Together, these foundational components to deep Web learning undergird *virtual simultaneity*, defined as the condition "in which many things are [simultaneously] being considered in the context of each other and in which *conceptual wholes greater than the sum of the parts* can form" (Spiro, 2006e, p. 2). The simultaneity is virtual, not temporal, in the sense that it is within a functioning cognitive space. This is a core aspect for Post-Gutenberg learning, through which learners experience information in a kind of virtual conceptual simultaneity, which, in concert with cognitive spreading activation, allows connections to be noticed that would not be noticed otherwise. It facilitates multiple conceptual comparisons and contrasts, allows for increasingly complex but cognitively manageable learning, provides an acceleration of the acquisition of experience, and develops open knowledge structures that can be tailored to new contexts. The speed increases outlined above have resulted in a learning environment where virtually simultaneity is not only possible, but may be common.

While very little empirical evidence exists for this emergent learning phenomenon, our recent demonstration case study provided evidence of the type of learning we describe above. For instance, the concept of virtual simultaneity was exemplified well in an early session of the study. While learning about climate change, the subject navigated quickly through successive articles in the NY Times global warming section, the subject scanned articles about the New Hampshire ski industry, autobahn speed limit considerations, carbon sequestration, and Pacific Islanders' concerns over rising ocean water. Though seemingly unrelated, this progression of articles one after another lead directly to the learner recognizing and documenting the importance of "selfishness" and "local recognition" as two important concepts in his understanding of climate change. We submit that the speed with which information can be accessed and the precise targetability provided by modern search engines on the Web directly facilitated such rapid conceptual development in a way that no other medium could. In this case, there was clearly a *loose* connection made among what were otherwise *heterogeneous* resources.

Two specific benefits arise from such loose associations and resultant conceptual development. First, the learner begins to appreciate the *conceptual variability* inherent to ill-structured domains. It becomes clear that though similarities exist across the disparate examples, they are not exactly the same. The nuances of New Hampshire residents' concerns with its ski industry cannot be mistaken for the concerns of Pacific Islanders'; these examples are not interchangeable. Fast nonreductive conceptual induction safeguards the conceptual rough edges that are desirable when learning concepts in ill-structured domains. These rough edges directly facilitate the second benefit: *flexible use.* When faced with situation specific need for the concept of selfishness or local recognition, the learner will be well prepared to select an appropriate prototype example (or examples) for application, based on both the similarities and differences that have been preserved among the candidates.

The development of several even more complex knowledge structures related to climate change were also apparent in our study. Among them, consider the concept of carbon markets, about which the subject had minimal prior knowledge at the onset of the study. However, during early research sessions, a complex understanding of carbon markets developed quickly, including the varying effects of mandatory and volunteer cap and trade systems; the Chicago Climate Exchange; related government inclinations (from the United States, European, and Chinese governments); and corporate interests. The subject considered the benefits and drawbacks of carbon markets, from the innovations that were directly credited to Clean Development Mechanism applications, to the inherent waste that carbon market critics argued. Ideas about why (typically anti-regulatory) US business interests are actually calling for more federal regulation in this arena were considered, and proposals that markets may not be able to cure the problem, given some assertions that climate change is the "greatest market failure" ever, were examined.

The implications of this specific example for deep learning in an ill-structured domain are two-fold. First, imagine trying to gather the resources to "instruct" a learner about the topics outlined above, and then completing this task in just a few hours. Any reasonable analogous approximation of the time necessary to replicate this information with traditional resources would be *many* times greater. Examination of a knowledge structure this complex and ill-structured cannot otherwise be accomplished without a learning environment like the Web, its specific affordances, and the skills and mindset outlined above. However, even more important was the evidence that this knowledge was later *flexibly reassembled*. In one of the final research sessions, in the context of how to change individual behavior to address climate change, the learner recombined several of the ideas about carbon markets with concepts from elsewhere (e.g., capitalism and economics) to propose the use of cap and trade systems for individual energy consumption. When considering the impact higher demand, lower supply energy may have on home energy use, the subject adapted the concept of lower effective per-unit carbon costs from carbon markets (and how mandated versus volunteer caps impact the level of incentive provided) with the profit considerations of utility companies to propose how the adoption of a "personal" cap and trade system for home energy would differ from those currently in place in industrial carbon marketplaces. This thought experiment served to both strengthen his understanding of industrial cap and trade systems (through revisitation of the related ideas) and provided key insights into some of the economic considerations needed to better understand issues related to his inquiry into individual climate change behavior. A more detailed accounting of both learning experiences is provided in DeSchryver & Spiro (in preparation). In sum, this demonstration case study suggested a clear relationship between the way that the material about carbon markets was learned and how it was later flexibly applied.

The level of complexity varied widely for the ideas encountered by the subject over the course of our study. However, he examined several more broadly ill-structured concepts, identified their inter-relationships and integrated them into an evolving and complex knowledge structure of climate change. These included:

- The role of capitalism/consumerism in climate change
- The mixed messages of corporate climate change agendas (e.g., Wal-Mart)
- The ever-changing nature of religion as it relates to climate change, and how "religious" perspectives often differ from the theological and philosophical considerations
- The educational implications of changing climate related behavior
- The complex relationship between climate change mitigation and adaptation
- Technology as both a climate change "cause" and "cure"

- The nascent eco-biz industry and related alternative fuel considerations
- The role and impact of international agencies (e.g., IPCC) and studies (e.g., Stern Report) in climate change
- Why the US and Europe have decidedly different approaches to climate change (both individual and governmental)
- The relationship among supercomputers, modeling, and climate change
- The role of media as it relates to climate change

It is important to note the extent to which each of these ideas interconnected with the others. For instance, the concept of religion was encountered several times. The subject developed an understanding of how both personal and institutional religious considerations shape issues related to climate change in powerful ways, and cannot be disconnected from policy and personal behavioral decisions. At the same time, these ideas demonstrated irregularity across instances, a hallmark of ill-structured concepts that differentiate them from complex, but well-structured concepts. For instance, early in the study, it was determined that several key religious institutions had begun to support policies to aggressively combat climate change. After having seen multiple examples of this positive support, the *temptation to generalize* on the part of the subject could have been very high (e.g., he could have generalized the concept that religious organizations support aggressive policies to mitigate climate change). However, a few sessions later, information about how one key religious institution had reversed its position was encountered. The ability to recognize and appreciate the irregularities that exist for concepts applied in ill-structured domains is critical, and directly facilitated by deep Web learning; learning in this way disables the temptation to over-generalize by inculcating a mindset that "it's not that simple."

COGNITIVE LOAD THEORY

While we find the above learning outcomes impressive, it may well be that this method of learning is just *hard*, or cognitively demanding. How, then, can we ensure that more people will be able to achieve these outcomes without overwhelming cognitive demands? We will answer this question through the lens of Cognitive Load Theory (CLT), a framework often utilized for just such concerns in learning.

CLT has been a leading framework for the study of human learning (e.g., see Sweller, van Merrienboer & Paas, 1998; van Merrienboer & Sweller, 2005). At the heart of CLT is a limited working memory for novel information and procedures, which demonstrates no such limitation when information is retrieved from long-term memory and related schemas (Ericsson & Kintsch, 1995). CLT assumes that long-term memory has unlimited capacity and that learning only occurs when changes in long-term memory have occurred (Kirschner, Sweller, & Clark, 2006). Cognitive load is calculated by the additive relationship among *intrinsic, extraneous,* and *germane* cognitive load (Paas, Renkl & Sweller, 2003; Sweller, van Merrienboer & Paas, 1998; van Merrienboer & Sweller, 2005). Intrinsic cognitive load is based on the fundamental characteristics of the material to be learned, most importantly, the number of elements that have to be considered simultaneously for successful learning (called *element interactivity*). Extraneous cognitive load is the *ineffective* load imposed by poor decision making related to the organization and presentation of information to be learned. Germane cognitive load is *effective*, in that it requires the “mindful engagement” of the learner with what is most essential to enhancing learning. Both extraneous and germane cognitive load are considered in CLT to be under the control of instructional designers. The ideas of CLT have been examined in a number of experiments that have confirmed the theory’s predicted relationship between kind of load and success in learning for different instructional designs.

In recent years, these basic ideas have been developed and extended to incorporate the demands of “real-life” tasks and the complex learning they often represent (van Merrienboer & Sweller, 2005). For example, the role of “chunking” by experts in reducing the number of interacting elements that results in lower effective intrinsic load, is increasingly of interest. CLT researchers have also begun to examine the effect of motivation on cognitive load in real-life learning and training contexts (e.g., see Pass, Tuovinen, van Merrienboer & Darabi, 2005).

Learning of the depth and complexity we describe in the section above has several cognitive load implications. Often, the total cognitive load is high. But, this heightened load should not always be avoided, given the potentially deleterious effects to learning from oversimplifying complex material (Feltovich, Coulson & Spiro, 2001; Spiro, Feltovich, Coulson & Anderson, 1989). It does no good to ignore *necessary* learning difficulty. When high cognitive loads for learning in ill-structured domains are encountered, they primarily derive from the nature of the material itself, or its intrinsic cognitive load. We have no choice but to acknowledge that this is the case, and work with it. Whereas, CLT has recently expanded and developed to address complex learning by “artificially” reducing element interactivity to reduce intrinsic cognitive load, since “understanding complex information may not be necessary or even possible in the early stages of learning” (van Merrienboer & Sweller, 2005, p. 157), we do not advocate this approach for ill-structured domains.

If intrinsic cognitive load in an ill-structured domain is high, artificially reducing the complexity in early learning is dangerous in two ways. First, with respect to the local concept, early simplifications interfere with the later acquisition of complexity (Feltovich et al., 1989, 1997, 2001; Spiro, Coulson, Feltovich, & Anderson, 1988; Spiro, Feltovich, Coulson, & Anderson, 1989). Second, such simplifications inculcate a reductive mindset, in general. We need to learn how to deal with complexity and ill-structuredness. Learning in and about ill-structured domains is hard and requires mental effort. Boiling these ideas down for simple presentation makes the ideas easier to learn (and easier to teach and assess), but does not facilitate the situation specific, interconnected, context dependent, flexible assemblies of knowledge that are necessary for learning in ill-structured domains.

In other situations, cognitive load may appear to be higher than it actually is. We present two reasons why this is case. First, in the following section, we revisit the concept of cognitive load and explore how it must be reconceptualized in order to better apply to ill-structured concepts, deep Web learning, and the Post-Gutenberg Mind. This reconceptualization mitigates some of the cognitive load concerns by arguing that common sources of extraneous cognitive load in well-structured domains actually represent germane load in ill-structured domains. Then, in the section thereafter, we discuss how cognitive load may be ameliorated by the specific kinds of nonrestrictive and nonreductive supports that are available and even intrinsic to deep learning on the Web.

COGNITIVE LOAD THEORY REVISITED

We find the evolution of CLT to be impressive in its consideration of expertise, real-life tasks, and complex learning. However, given that in its application, CLT has primarily been concerned with "relatively well-structured procedural and conceptual domains" (van Merrienboer & Sweller, 2005, p. 156), we propose that a reconceptualization is necessary in order for CLT to apply to real-life learning tasks in ill-structured domains, especially in deep Web learning. (See also Gerjets and Scheiter, 2003, for their useful suggestions about the relationship between cognitive load, learner goals, and individual processing strategies in hypertext learning environments.) We present this reconceptualization with four distinct arguments. First, we highlight how ill-structured domains and well-structured domains are dissimilar and how the goals for learning in each must also necessarily differ. Second, we outline a reconceptualized germane cognitive load that is more appropriate for learning in ill-structured domains. Third, we discuss how this reconceptualization underscores our position that *what is considered extraneous cognitive load in well-structured domains is often germane in ill-structured domains*. Finally, we argue that the Web represents a quintessential way to optimize the ratio of extraneous load to our new conceptualization of germane load for learning in ill-structured domains.

Learning Goals in Ill-Structured versus Well-Structured Domains

The learning goals in well-structured and ill-structured domains are not the same. This stems from the structural differences that exist between them. Well-structured material, even that which demonstrates complexity, exhibits orderliness and regularity that underscore the goals for learning. It is always possible to present essential information or known procedures for well-structured material. Answers exist to questions posed in well-structured domains. Therefore, the primary goal for learning in well-structured domains is the construction and automation of schemas. Traditional CLT, primarily working within well-structured domains, therefore defines germane cognitive load to comprise the mental effort devoted to such construction and automation (van Merrienboer & Sweller, 2005).

However, the goal for learning in ill-structured domains is something different, focusing on the construction of open and flexible knowledge structures for situation specific application. This is primarily due to the *irregularity* that concepts and phenomena demonstrate across instances and applications, such that pre-specifying the conditions under which knowledge will be used is not possible. Because of this irregularity, emphasizing only the acquisition and automation of prepackaged schemas does not provide the flexible knowledge structures required; schemas alone cannot prepare learners for the wide scope of application needed, since essential information and known procedures do not exist. Since there are not specific answers with universal application to questions posed in ill-structured domains, preparing the learner for situation-sensitive development of "schemas-of-the-moment" is of utmost importance. (For a more detailed presentation of the special qualities of learning in ill-structured domains, see Spiro & DeSchryver, in press; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987; Spiro, Feltovich & Coulson, 1996).

Germane Cognitive Load for Ill-Structured Domains

The concept of germane cognitive load must therefore be reconceptualized in order to be consistent with the learning goals for ill-structured domains. In general, we encourage mental efforts that resist oversimplification and resist reductive thinking. In this way, we advocate an emphasis on learning activities that support new constructions of indefinite numbers of situation sensitive assemblages and not retrieval of precompiled schemas or templates from long-term memory. These activities comprise a more appropriate conceptualization of germane cognitive load for ill-structured domains, and should include:

- Recognizing interconnections
- Criss-crossing the knowledge landscape
- Experiencing multiple perspectives and representations
- Testing candidate generalizations with a presumption of "it's not that simple" until proven otherwise
- Seeing patterns of context dependence
- Identifying how surprising similarities and surprising differences unfold

Recognizing That Extraneous Cognitive Load Activities in WSDs Often Appear as Germane Cognitive Load in ISDs

Based on traditional conceptions of CLT, the activities we have outlined that are crucial to learning in ill-structured domains represent extraneous cognitive load when learning in well-structured domains. As well they should. When essential information is known, or a correct procedure available (as is typically the case for well-structured material), it should be presented to learners in a way that maximizes their ability to acquire, update, and automate schemas. Criss-crossing the knowledge landscape to find essential information would increase extraneous load dramatically, wastefully, and unnecessarily.

The reverse is also true. Schema construction and automation (considered germane to learning in well-structured domains) is extraneous to the goal of flexible learning in ill-structured domains. It is equally as wasteful to construct and automate schemas in ill-structured domains as it is to cross-cross well-structured domains looking for known information. Since tailored "in-the-moment" assemblages of are most germane to learning in ill-structure domains, intact schema retrieval is minimized. Any time spent constructing intact schemas is essentially wasted. In fact, use of intact schemas tends to compartmentalize knowledge in a way that works against the goals of flexible knowledge, by blocking the ability for the learner to properly recognize the inherent interconnectedness in ill-structured domains (Spiro et al., 1991). In this way, schema construction not only represents extraneous load for learning in ill-structured domains, but also undermines a primary process of flexible knowledge construction.

The Web Provides Essential Ways to Optimize Germane Cognitive Load for Learning in Ill-Structured Domains

Our conceptualization of germane cognitive load activities for ill-structured domains will also appear to represent extraneous cognitive load when considered for traditional linear media. However, with hypermedia and especially now the Web, we finally have learning environments that accommodate advanced knowledge acquisition in ill-structured domains and work to make our proposed mental efforts germane. In fact, the affordances of the Web keep extraneous load *much lower* for learning activities that are specifically relevant to ill-structured domains than they would otherwise be with traditional media.

For instance, if you accept that criss-crossing non-linear irregularly interconnected knowledge is essential to learning in ill-structured domains, what better medium exists than the Web? Consider again how long it would take for a learner to find print media in a library even closely approximating the expansive and up-to-the-minute resources outlined above for climate change. Then, imagine how long it would take to begin to recognize the intricate interconnectedness among these myriad resources. The extraneous load requirements would be overwhelming with traditional media. However, on the Web, interconnectedness is inherent and the resources virtually unlimited. What is the optimal use of cognitive load resources to create interconnections among disparate information resources, card catalogs and indexes, or the instant-access, fully searchable, non-linear Web? There is no comparison. The Web is ideal for learning in this way.

COGNITIVE LOAD CONSIDERATIONS FOR SPECIFIC ASPECTS OF DEEP WEB LEARNING IN ILL-STRUCTURED DOMAINS

As we have noted, many aspects of deep Web learning in ill-structured domains that are germane might, in well-structured domains or with traditional linear media, be considered extraneous, and vice-versa. In this section, we discuss several aspects of deep Web learning in ill-structured domains and how they may help to maximize the ratio of germane cognitive load to extraneous cognitive load. Again, we present these ideas as *what is possible* for deep learning on the Web not *what is* the case for everyone. Continued research that examines these phenomena more specifically and under more controlled circumstances will help identify the conditions under which they apply more broadly, and how to best prepare novice learners for deep Web learning in ill-structured domains.

LICRA Searches

Learner-initiated, complex, reciprocally adaptive (LICRA) searches are a core feature to successful deep Web learning in ill-structured domains. These searches promote active involvement from the learner, require heightened attention, and emphasize the need for value determination and judgment. Given this additional effort required to generate successful LICRA searches, it should be expected that associated cognitive loads are rather high. Indeed, CLT often associates searching of any kind-- for information needed to complete a learning task, for solutions, or for referents in an explanation-- with extraneous cognitive load (Paas, Renkl, & Sweller, 2003; van Merrienboer Sweller, 2005).

However, consistent with the above account of how cognitive load applies to ill-structured domains, this effort represents *germane* cognitive load. LICRA searches are part of the learning process and cannot be viewed separately. When learners use a LICRA phrase, they create implicit interconnections among resources. The iterative nature of these searches also facilitates criss-crossing the conceptual landscape in order to construct a better sense of the whole. As a result, when compared to following embedded hyperlinks or scanning through a single list of Google results, these iterative search techniques promise a greater payoff.

Extraneous cognitive load concerns about hypertext learning are somewhat ameliorated by LICRA searching, as well. The decision-making that is “required” by the visual cue of an embedded hyperlink may serve to increase extraneous load, especially if multiple links appear on the same page (DeStefano & LeFevre, 2007). This issue does not exist for LICRA searches, because they result from an internal, somewhat spontaneous, assignment of importance on the part of the learner. The same “interruptive” quality does not exist for LICRA searches as it does for embedded links. There is also some concern that following hyperlinks, especially for a long time or to “semantically distant information” (DeStefano & LeFevre, 2007, p. 1620) increases cognitive load and reduces comprehension. However, criss-crossing, or following links, either embedded or learner initiated, is a core feature of deep Web learning when learning in ill-structured domains. And, many forms of extraneous load associated with the criss-crossing supported by LICRA searches should be increasingly mitigated by the growing body of adjunct learning aids (see below) that help to make explicit the choices and relationships that emerge while exploring the knowledge landscape. We also envision that as learners become more effective at LICRA searching, the “after-the-fact” ratio of germane to extraneous load will also optimize (i.e., more LICRA phrases will yield useful information and less will be “dead-ends”).

It should be noted that there are well-structured skills that are necessary in order for learners to perform successful LICRA searches. For instance, using quotation marks to target exact phrases, employing Boolean logic, searching a specific site, using a tilde to return related items in a search, and using the “link:” phrase to determine backlinks, are all useful skills that should be taught to and practiced by Web users. We support the notion that the automation of schema for such skills is essential to good LICRA searching and should be done with the lowest possible extraneous cognitive load.

Serendipitous Learning

Serendipitous learning comprises an accidental encounter with seemingly unrelated or useless information that then becomes useful. Such serendipitous learning is automatic, unconscious, and spontaneous in nature, inherently requires no conscious mental effort, and thus demonstrates a very low cognitive load requirement. While the value of making serendipitous connections between unrelated ideas is not new to hypertext research (e.g., Bernstein, Bolter, Joyce, and Mylonas, 1991), it has often been a form of “quasi-random” knowledge association, given the finite amount of information in closed hypertext systems or when just following links provided on a web page. However, in deep Web searches utilizing LICRA methods, serendipitous information can, and does, emerge at any time. The likelihood of the occurrence of serendipitous learning increases exponentially as the speed of access to information increases, as Web users search more efficiently, and as the landscape of resources available becomes, for practical purposes, unlimited. This exponential increase in potential random encounters requires no additional effort on the part of the learner, but is often significant to the learning process. Our recent research demonstrated several points at which serendipitous finds resulted in significant conceptual breakthroughs and novel interconnections of information for the learner (DeSchryver & Spiro, in preparation).

Such serendipitous learning can happen at any time on the Web, including moving “backwards” in the search process. For instance, in our recent study, it was common for the learner to open several new browser tabs during LICRA searches to accommodate multilevel iterative search phrase development. Several times, after a "stopping-point" in this process was reached, and while returning to his original search results (e.g., "backing out" of the iterative searches), the subject noticed information that did not seem relevant when it was first viewed but that was particularly useful in the context of the new information he had since encountered. This new relevance may have occurred as a result of the accumulated context. However, the benefits of "considering," or reviewing, information multiple times within a relatively short period need to be explored.

Resource Evaluation

The evaluation of a Web resource for authority and accuracy typically has extensive extraneous cognitive load implications. Learners are often provided with rubrics containing several questions to answer for each Web resource they encounter. For example: Is it a personal page? What type of domain is it from? Who wrote the page? Is it dated? Is it current enough? What are the author's credentials? Are sources documented? Are there links to other sources? (see Finding, 2008, for the full and much more exhaustive list). The use of such guidelines requires very high extraneous cognitive loads. And, while such rubrics may be valuable for young or introductory learners, our recent study provides evidence that this process may become fully integrated into the learning process for advanced learners.

One reason for such integration is that the Web is full of "trusted aggregators" that reduce the evaluation necessary. For instance, the New York Times has a list of articles related to climate change. At the same time, especially in extended learning on the Web, learners will visit the same sites over and over. Subsequent visits to a trusted site (including what are often visits to topically disparate sub-nodes in the site) require no additional evaluation.

However, more significantly, we submit that the integration of resource evaluation results primarily when the learner becomes adept at seeking out multiple representations of one concept while learning about it. Through recognizing the similarities and differences among the multiplicity of resources, it quickly becomes apparent which resources are trusted and which are not, without working through a guideline of static questions about each resource. In this way, resource evaluation is *fully integrated into the learning process* for the advanced learner by an often unwitting method of *triangulation*. Each site visited not only provides new information, new contexts, new representations, and new perspectives that are germane to learning, but also tightens the criteria for filtering out resources that do not reflect the quality, accuracy or credibility of acceptable sites. From a cognitive load perspective, an extraneous load requirement has been transferred to a germane learning activity.

Blogs

The nature of the information found during deep Web learning has significant implications for the learner's cognitive load. For instance, blogs now increasingly find their way into Web search results. The casual form of information typically encountered in blogs has largely been considered useless for serious knowledge inquiry (e.g., see Head, 2007). However, we found that several categories of blogs were examined during our recent study of deep Web learning, running the gamut from factual to opinionated. Analysis of the various types of blogs that were used, as well as their interactions with the differing stages of meaningful learning (Sheull, 1990), indicated that blogs can be quite valuable to the learning process and that the related cognitive load requirements vary.

For instance, the use of blogs in early stage learning (fact-based) does not seem beneficial. The above methods for resource evaluation require more authoritative resources for fact-finding. Though many excellent factual blogs exist and were encountered by the subject during early stage learning, most were filtered out by resource triangulation methods. It seems additional extraneous cognitive load would be required to determine the credibility of facts in a blog, whereas the triangulation techniques for resource evaluation for other more authoritative factual sites require less effort. Evaluating blogs for “facts” just does not seem worth the extra mental effort at this stage in learning.

However, during latter stages in the learning process (involving more problem-solving and abstract thinking) triangulation methods for resource evaluation seemed to value the opportunity for “idea play” that less factual blogs provided. We submit that taking into account the speed with which ideas from different blog sites can be experienced on the Web can result in a dialogical interaction among the user and multiple blog sites. In this way, the learner can agree with some authors and disagree with others; accept some points, and discount others; all the while developing his or her own ideas through arguing, counter-arguing, and the related combinatorial idea play. In this way, the voices in blog entries are *virtually synchronized* and provide great potential for deep learning of ill-structured domains on the Web. At the same time, the extraneous load associated with early (fact-based) use of blogs is minimized, since the interactions with blogs become germane during creative knowledge assemblies. Extraneous cognitive load is also further reduced by the conversational text found in most blogs that will often be easier to comprehend for the learner than other, more authoritative resources. Examples of this type of learning are provided in DeSchryver and Spiro (in preparation), where the use of blogs was directly responsible for multiple significant conceptual breakthroughs on the part of the learner.

Adjunct Online Tools

Cognitive support tools for deep learning on the Web are widely available. From Web text highlighting to page specific sticky notes for individual or group use, adjunct *online tools* abound, and new ones are released regularly. The number of modern tools to support deep Web learning dwarfs those available for traditional text or lecture-based environments. The unprecedented availability of these adjunct supportive aids also has significant cognitive load implications.

External memory aids like Clipmarks (http://www.clipmarks.com) make it effortless to save whole pages as well as small segments of pages (including images and video) in a personalized database. The information contained therein can be accessed by keyword, Boolean search, or chronologically, and increases the ease with which learners can criss-cross and revisit the information. This facilitates the recognition of interconnections, multiplicities, and differing contexts that are critical to the acquisition of flexible knowledge (Spiro & Jehng, 1990). At the same time, tools such as Google History and Trailfire, or even just concerted use of the tabs available in modern browsers for individual sessions, allow users to document and easily trace their paths through the web. While keeping extraneous cognitive load low relative to navigation (e.g., you can never really get lost), these services also have the potential to dramatically support the additional (germane) meta-cognitive activities that deep Web learning affords, by making explicit the paths of inquiry for later review, with little or no additional extraneous load.

Though not a specific tool, the functionality of *tagging* (assigning keywords to content of interest) in most online cognitive tools also increases the potential benefits of deep Web learning. Most contemporary Web-based content management systems (e.g., Clipmarks), utilize this feature extensively. Tagging is an organizational activity that requires the assignment of meaning, a task that therefore represents germane cognitive load. Tagging information can represent an elaboration that fosters the encoding of long-term memories (Budiu, Pirolli, & Hong, 2007; van Merrienboer & Sweller, 2005). However, more important to learning in ill-structured domains, the application of multiple tags facilitates learner recognition of interconnections that may exist among the newly-discovered information and previous information that has been similarly tagged, by promoting the construction of flexible knowledge. And, as Sinha (2005) noted, the practice of applying multiple tags to information may actually require a lower cognitive load than assigning information to a single category. She argued that upon encountering worthwhile information, multiple semantic concepts are typically activated in a learner. When forced to assign the information to one category, significant cognitive load is spent determining the *best* category, often resulting in what she called "post activation analysis paralysis" (para 16). However, the multiplicity of tagging allows learners to freedom to assign information to all related semantic concepts that are activated. She claims that it "taps into an existing cognitive process without adding much cognitive cost" (para 19).

There are also broader benefits to be accrued from tagging. For instance, Weinberger (2007) asserted that tagging *en masse*, combined with sophisticated data mining and search technologies, will facilitate better reconstructions of the implicit meaning of information on the Web. When available as part of the search process, this "meaning" will greatly focus searches for everyone, thus lowering any extraneous cognitive load related to filtering the results.

The Question of Motivation

Recent developments in CLT have begun to integrate the importance of motivation, especially when considering "real-life," extended time tasks (Pass, Tuovinen, van Merrienboer & Darabi, 2005; van Merrienboer & Sweller, 2005). And, while Astleitner and Wiesner (2004) raised concern for how a high density of motivational strategies explicitly designed for instructional settings may lead to negative effects on cognitive load, we have found that motivation in deep Web learning is largely inherent, not an additional learning component that vies for space in working memory. Learners in the midst of deep Web exploration find it to be fun, satisfying, and reinforcing to find information so quickly and easily (e.g., see DeSchryver & Spiro, in preparation). The specific cognitive load implications for motivation are just beginning to emerge. However, as Pass et al. (2005) noted "meaningful learning can only commence if training experience is coupled with the motivation to achieve well" (p. 26). More specifically, higher levels of learner motivation have the potential to increase the use of mental efforts that are germane to the learning outcomes.

Deep Web learning affords such increased motivation, and it was manifested in surprising ways in our recent study. Several times the subject noted his excitement about a particular path of inquiry, new and promising search phrases based on ideas from the current page, or a significant conceptual breakthrough. In a few cases a sort of learning *momentum* affected his motivations. Why? Although the exact processes are speculative, we offer three ways deep Web learning appears to increase motivation, through attention, choice, and speed.

In Keller's (1987a; 1987b; 1999) Model of Motivation Design, he outlined four ways to promote and sustain motivation in the learning process: Attention, Relevance, Confidence, and Satisfaction (ARCS). Each of these elements can be supported by deep Web learning. For instance, Keller noted that *attention* and subsequent motivation could be gained through novel, surprising, incongruous, and uncertain events. We argue that novel, surprising, incongruous, and uncertain *ideas* discovered in the course of deep Web learning have a similarly enhancing effect on learner attention. And, since the Web interactions are not "designed" elements, they should not increase extraneous cognitive load, so that any increase in attention and effort likely serves to optimize germane cognitive load.

In addition, as Brophy has noted, much of what is known about optimal conditions for motivation cannot be easily applied in classrooms (in Gaedke & Shaughnessy, 2003). However, these very same ideas can and often do apply in deep Web learning, such as *learner control*. In typical classrooms learner choice is minimized; however, considerable choice is afforded to Post-Gutenberg learners. Thev learn whenever and wherever they want. They choose what search phrases to use. They choose which results to visit. The assemblage of knowledge is personal in every way. The impact of this type of learning on personal attributions, expectations, and self-efficacy needs to be explored in more detail. However, we propose that once learners begin to feel empowered (which does not take long), they begin to *believe* that they can achieve their learning goals.

Finally, *speed* is essential to learner motivation on the Web. Everything happens fast. Resources are available in an instant. However, even more significant, our recent study of deep Web learning demonstrated a *quick transition* from early "fact-finding" to the *advanced stages of meaningful learning* that involved rapid interconnectedness and abstract/problem based thinking (Sheull, 1990). Accordingly, the subject indicated more excitement about these latter stages. The speed with which new information is available also impacts motivation; the learner can read reaction to yesterday's Senate hearings on climate change today, or in some cases can evaluate information in real-time. Access to *information this timely* empowers the learner, and may even make them feel like they know something others do not (including teachers).

Together, the impact of these motivational considerations on cognitive load needs further exploration, particularly for deep Web learning. However, we envision increased motivation, inherent in the learning process itself, indirectly providing substantial benefits to the process through increased germane mental efforts.

CONCLUSION

The chapter discusses how deep learning on the Web provides affordances that are well matched to the learning goals and requirements for flexible knowledge construction in ill-structured domains. In so doing, we have outlined a reconceptualization of germane cognitive load that is more appropriate for learning in ill-structured domains than that conceived by traditional Cognitive Load Theory. This new perspective makes it clear that activities that are germane to learning in ill-structured domains are often extraneous in well-structured domains, and vice-versa. We have also discussed how specific aspects of deep Web learning in ill-structured domains help to optimize the ratio of germane cognitive load to extraneous cognitive load, including LICRA searching, serendipitous learning, resource evaluation, blog use, the availability of adjunct cognitive tools, tagging, and learner motivation.

Not everyone is prepared to take advantage of the benefits we have outlined. Nor do all domains of knowledge benefit from unfettered exploration in online multimedia environments. Additionally, cognitive load may be increased at first for novice Web learners. However, for ill-structured domains, deep Web learning holds great promise. The automatization of the basic skills required to successfully learn in depth on the Web happens quickly as users become more familiar with basic search options. The learner's skills improve with practice, and soon these skills are incorporated effortlessly within higher-level aspects of learning (e.g., LICRA searching and integrated resource evaluation), similar to how an advanced driver uses a steering wheel while navigating during rush hour. While expert drivers steer unconsciously and attend to the landscape around them, so, too, will expert searchers direct themselves around the vast knowledge landscape of the Web without concerted effort. The automaticity of simple search skills leads to decreased extraneous cognitive load, freeing up resources for activities that are germane to flexible knowledge acquisition in ill-structured domains.

We are confident that the learning we describe above can become a reality for many learners. However, while we have concentrated on the benefits that deep Web learning can provide, obstacles to its success remain. For instance, the sheer quantity of resources available on the Web imposes a challenge. Learners may, even with the assistance of adjunct cognitive tools, drift away from relevant search results to information that is, in effect, extraneous to their efforts. In order to address these issues, we anticipate the need to develop loose meta-data structures similar to those employed in Cognitive Flexibility Hypertext systems (e.g., see Spiro, Collins & Ramchandran, 2007).

In addition, managing the *personal knowledge landscape* constructed by individuals immersed in deep Web learning may require support beyond what current adjunct online tools provide. Such support may take the form of more integrated tools capable of reducing the associated extraneous cognitive load. One such possibility would be the development of representative dynamic visual displays. We see the need for evolving network mind-maps, developed in an ongoing fashion with input from both the learner and the software in use. The information could be tagged by context so that the visual display highlights different information in different contexts, demonstrates the interconnectedness among ideas, facilitates revisitation, and provides significant meta-cognitive learning benefits. For example, this system could allow for three-dimensional mind-maps, each node mashed-up with the information from a Clipmarks-like database and the relevant Google History details, including visual representations of the interconnections that have formed.

FUTURE RESEARCH

To conclude, we offer the following: The Web will change the way that we think and learn, and these changes will be dramatic. It is inevitable. The timing of this revolution is fortuitous, since we are faced with increasingly complex and ill-structured educational and societal issues, both local and global in scale. Consider the difficulty we face assuming, as our forefathers did, that we have an "informed constituency" to support democracy. For example, climate change, health care, and globalization are "grand social challenges" that an informed electorate should understand to a much greater extent than is currently the case. These issues and others like them demonstrate ill-structuredness and they therefore require high levels of intrinsic cognitive load to understand. We believe that with concerted research efforts, ways for the Web to make learning about such issues cognitively manageable will result.

As a field, we need to be proactive in thinking about how to ensure that this happens. This chapter is provided to encourage more researchers to examine this phenomenon in earnest. Myriad research opportunities and lines of inquiry exist and beg examination under both well-controlled and "real-life" conditions to determine the circumstances, knowledge domains, and learner characteristics for which new ways of learning will apply most broadly. What are the best ways to ensure that learners approach deep Web learning with an opening mindset? How will we best use tagging, LICRA searches and blogs to develop flexible knowledge appropriate to the challenges we face? Is the cognitive load for LICRA searches less than that for embedded links? If not, do the benefits outweigh the costs? What is the best balance of successful serendipitous encounters to dead-ends when criss-crossing the Web's knowledge landscape? Does a learner need to develop a certain level of expertise in the basic skills of deep Web learning in order for the motivational benefits we have outlined to emerge? These questions and many more require the attention of learning science researchers in order to better understand ongoing changes in the ways we teach, learn, and think.

References

Astleitner, H., & Wiesner, C. (2004). An integrated model of multimedia learning and motivation. *Journal of Educational Multimedia and Hypermedia, 13*, 3-21.

Bernstein, M., Bolter, J.D., Joyce, M., & Mylonas, E. (1991) Architectures for volatile hypertext. *Proceedings of Hypertext' 91*, ACM Press, San Antonio, Texas, December, 241-260.

Budiu, R., Pirolli, P., Hong, L. (2007). Remembrance of things tagged: How tagging affects human information processing. *Palo Alto Research Center.* Retrieved January 17, 2008 from http://asc.parc.googlepages.com/2007-09-12-tagmemory-12-blogged-vers.pdf

DeSchryver, M. & Spiro, R.J. (in preparation). Nonlinear knowledge acquisition in a post-Gutenberg world: An examination of emerging constructs for deep learning on the Web.

DeStefano, D. & LeFevre, J. (2007). Cognitive load in hypertext reading: A review. *Computers in Human Behavior, 23*, 1616-1641.

Ericsson, K. A. & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102*(2)*,* 211-245.

Feltovich, P.J,, Coulson, R.L., & Spiro, R.J. (2001). Learners' understanding of important and difficult concepts: A challenge to smart machines in education. In P.J. Feltovich & K. Forbus (Eds.). *Smart machines in education.* Cambridge, MA: MIT Press.

Feltovich, P. J., Spiro, R. J., & Coulson, R. L. (1989). The nature of conceptual understanding in biomedicine: The deep structure of complex ideas and the development of misconceptions. In D. Evans & V. Patel (Eds.), *The cognitive sciences in medicine* (pp. 113-172). Cambridge, MA: M.I.T. Press.

Feltovich, P.J, Spiro, R.J., & Coulson, R.L. (1997). Issues of expert flexibility in contexts characterized by complexity and change. In P.J. Feltovich, K.M. Ford, & R.R. Hoffman (Eds.). *Expertise in context: Human and machine.* Cambridge, MA: MIT Press.

Finding information on the Internet: A tutorial, (2008). Retrieved February 10, 2008 from http://www.lib.berkeley.edu/TeachingLib/Guides/Internet/Evaluate.html

Gaedke, B. & Shaughnessy, M.F. (2003). An interview with Jere Brophy. *Educational Psychology Review, 15*(2), 199-211.

Gerjets, P., & Scheiter, K. (2003). Goals and strategies as moderators between instructional design and cognitive load: Evidence from hypertext-based instruction. *Educational Psychologist, 38*, 33-41.

Graff, M. (2003). Learning from web-based instructional systems and cognitive style. *British Journal of Educational Technology, 34*(4), 407-418.

Griffiths, J. & Brophy, P. (2005). Student searching behavior and the Web: Use of academic resources and Google," *Library Trends*, *53*(4), 539–554.

Head, A.J. (2007). Beyond Google: How do students conducts academic research? *First Monday, 12*(8). Retrieved January 15, 2008 from http://firstmonday.org/issues/issue12_8/head/index.htm

Jones, S. (2002). The Internet goes to college: How students are living in the future with today's technology. *Pew Internet and American Life Project*. Retrieved January 20, 2008 from http://www.pewinternet.org/PPF/r/71/report_display.asp

Keller, J. M. (1987a). Development and use of the ARCS model of motivational design. *Journal of Instructional Development, 10(3)*, 2 – 10.

Keller, J. M. (1987b). Strategies for stimulating the motivation to learn. *Performance & Instruction, 26(8)*, 1-7.

Keller, J. M. (1999). Motivation in cyber learning environments. *Educational Technology International, 1(1)*, 7 – 30.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.

Kuiper, E., Volman, M., & Terwel, J. (2005). The Web as an information resources in K-12 education: Strategies for supporting students in searching and processing information. *Review of Educational Research, 75* (3), 285-328.

Morville, P. (2005). *Ambient findability: What we find changes who we become.* Cambridge, MA: O'Reilly Media.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1-4.

Paas, F., Tuovinen, J.E., van Merriënboer, J.J.G., & Darabi, A. (2005). A motivational perspective on the relation between mental effort and performance: optimizing learners' involvement in instructional conditions. *Educational Technology, Research & Development*, *53*, 25–34.

Sheull, T.J. (1990). Toward a Unified Approach to Learning as a Multisource Phenomenon. *Review of Educational Research*, 60(4), 531-547.

Sinha, R. (2005, September 27). A cognitive analysis of tagging (or how the lower cognitive cost of tagging makes it popular). Thoughts About Cognition, Design, and Technology: Rashmi Sinha's weblog. Retreived December 12, 2007 from http://www.rashmisinha.com/archives/05_09/tagging-cognitive.html

Spiro, R.J. (2006a). The “New Gutenberg Revolution”: Radical new learning, thinking, teaching, and training with Technology…bringing the future near. *Educational Technology*, *46* (1), 3-4.

Spiro, R.J. (2006b). The post-Gutenberg world of the mind: The shape of the new learning. *Educational Technology, 46* (2), 3-4.

Spiro, R.J. (2006c). Old ways die hard. *Educational Technology, 46* (3), 3-4.

Spiro, R.J. (2006d). Approaching the post-gutenberg mind: The revolution is in progress. *Educational Technology, 46* (4), 3-4.

Spiro, R.J. (2006e). The “New Gutenberg Revolution”: Radical new learning, thinking, teaching, and training with technology…bringing the future near. *Educational Technology, 46* (6), 3-5.

Spiro, R.J., Coulson, R. L., Feltovich, P. J., & Anderson, D. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. *Tenth Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Erlbaum,. [Reprinted in In R. B. Ruddell (Ed.), *Theoretical models and processes of reading* (5th ed.). Newark, DE: International Reading Association, pp. 602-616.]

Spiro, R. J., Collins, B. P., Ramchandran, A. R. (2007). Reflections on a Post-Gutenberg Epistemology for Video Use in Ill-Structured Domains: Things You Can Do With Video to Foster Complex Learning and Cognitive Flexibility. *Video Research in the Learning Sciences.* Goldman, R., Pea R., Barron B., and Derry, S. (Eds.). Mahwah, NJ: Lawrence Erlbaum Associates.

Spiro, R.J. & DeSchryver, M. (in press). Constructivism: When it’s the wrong idea and when it’s the only idea. In T. Duffy & S. Tobais (Eds.). Mahwah, NJ: Lawrence Erlbaum.

Spiro, R.J. & DeSchryver, M. (in preparation). The new nonlinear reading comprehension: Deep learning on the Web and the post-Gutenberg mind.

Spiro, R.J., Feltovich, P.J., & Coulson, R.L. (1996). Two epistemic world-views: Prefigurative schemas and learning in complex domains. *Applied Cognitive Psychology*, *10*, pp. 52-61.

Spiro, R.J., Feltovich, P. J., Coulson, R. L., & Anderson, D. (1989). Multiple analogies for complex concepts: Antidotes for analogy-induced misconception in advanced knowledge acquisition. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 498-531). Cambridge, MA: Cambridge University Press.

Spiro, R. J., Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (1991). Knowledge representation, content specification, and the development of skill in situation-specific knowledge assembly: Some constructvist issues as they relate to cognitive flexibility theory and hypertext. *Educational Technology,31* (9), 22-25.

Spiro, R.J., & Jehng, J. (1990). Cognitive Flexibility and Hypertext: Theory and Technology for the nonlinear and multidimensional Traversal of Complex Subject Matter. In D. Nix & R. J. Spiro (Eds.), *Cognition, education, and multimedia* (pp. 163-205). Hillsdale: Lawrence Erlbaum Associates.

Spiro, R. J., Vispoel, W. L., Schmitz, J., Samarapungavan, A., & Boerger, A. (1987). Knowledge acquisition for application: Cognitive flexibility and transfer in complex content domains. In B. C. Britton & S. Glynn (Eds.), *Executive control processes*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Sweller. J. (1988) Cognitive load during problem solving: Effects on learning *Cognitive Science* 12, 157-285.

Sweller, J. (1994) Cognitive load theory, learning difficulty and instructional design *Learning and Instruction* 4, 295-312.

Sweller, J., van Merrienboer, J. J. G., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review 10*(3), 251–296.

Tremayne, M., & Dunwoody, S. (2001). Interactivity, information processing, and learning on the World Wide Web. *Science Communication, 23(2)*, 111-134.

Thompson, C. (2003). Information illiterate or lazy: How college students use the Web for research. *Libraries and the Academy, 3*(2), 259-268.

van Merrienboer, J.J.G. & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review 17*(2), 147-177.

Van Scoyoc, A.M. (2006). The electronic library: Undergraduate research behavrio in a library without books. *Libraries and the Academy, 6*(1), 47-58.

Weinberger, D. (2007). *Everything Is Miscellaneous*, New York: Henry Holt.