

# Applying Text Comprehension and Active Reading Principles to Adaptive Hyperbooks

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## Abstract

We show how cognitive and educational research and theory from the areas of text comprehension and "active reading" strategies can be applied to the domain of hypermedia textbooks ("hyperbooks"). We describe our work on the MetaLinks system, which is an authoring tool and web-based server for adaptive hyperbooks. In this paper we describe how findings from text comprehension research are incorporated into MetaLinks design features, and summarize formative studies of students using MetaLinks hyperbooks.

## Introduction

In this paper we show how cognitive and educational research and theory from the areas of text comprehension and active reading strategies can be applied to the domain of hypermedia textbooks ("hyperbooks"). Though corporeal books have important affordances not found yet in hypermedia books, content is increasingly cast in electronic forms, and more research is needed to understand the cognitive aspects of both reading and authoring hyperbooks.<sup>1</sup> Despite the large number of research studies completed and systems built in the area of hypermedia, very little of it is both based on cognitive theory and built upon empirical results from studies of learners, as we do here. We describe our work on the MetaLinks system, which is an authoring tool and web-based server for adaptive hyperbooks. In designing the software we have two primary goals. The first goal is to support active reading and learning strategies in on-line texts. The second goal is to take fuller advantage of the unique affordances of digital media and investigate new ways to author and read that are not possible in traditional texts. Here we describe how findings from text comprehension research are incorporated into MetaLinks design features, and summarize initial formative studies of students using MetaLinks hyperbooks.

Our theoretical basis comes in part from research in text comprehension and active reading. "Active reading" (Ohara 1996, Schilit et al. 1999, Roast et al. 2002) refers to a set of high level reading, searching, problem solving, and

metacognitive skills. We will sometimes refer to this general process as "active reading/*learning*" to reflect the fact that active readers of textbooks are proactively trying to construct new knowledge. Though active reading skills are important because they lead to more efficient and effective comprehension and information finding, these skills are not very advanced in many students (and adults), and it is important to support, scaffold, and teach these skills.

## Background: Text Comprehension and Active Reading

In recent times the traditional behaviorist view of reading as a decoding process leading to the passive acquisition of isolated facts and skills has been replaced with a more cognitively oriented view in which reading is an active, self-regulated meaning-construction process in which the reader interacts with text in a strategic way (Mannes & Kintch 1987, Kintsch 1998). Processing text is seen as a multi-level cognitive process. Text reading for comprehension is seen as a process of trying to maintain semantic coherence, i.e. fitting new information into existing knowledge structures. At a *local* level readers try to fit what are reading into the context of what they have recently read, making sense of the progression of related ideas. At a *global* level readers try to assimilate new information into prior knowledge, or accommodate prior knowledge to be consistent with the new information. Johnson & Afflerback's (1985) study investigates the process of constructing main ideas from texts, which is generally regarded as the essence of reading comprehension. This skill, though universally important to reading at all levels, is actually a complex set of skills that never fully develop in many readers. Brown et al. (1994) use of reciprocal teaching in classrooms relied in part upon having students work actively to create meaning from texts through collaborative and interpretive iterations.

Throughout the literature one of the primary factors determining reading behavior and outcomes is *background knowledge*. Readers who know more about a domain can more easily: comprehend content as they read, determine what they need to know, decide how to find what they need to know, and anticipate or predict what may come next. They can make bridging inferences when the flow of text lacks coherence, and construct macro-representations (overviews or summaries) of the structure of an entire topic or document (Kintsch 1998, Royer & Cunningham 1981). Because learners have different background knowledge,

<sup>1</sup> We acknowledge that in moving from paper to computer screen many affordances are lost (see Masten et al. 1997, Schilit et al. 1999) and we do not advocate for the replacement of paper texts with electronic ones, but we are of the opinion that: a) the movement of textual material to electronic form is momentous and inevitable and thus must be investigated, and b) electronic texts have the potential to support active reading in new and significant ways.

learning styles, and goals, and because each learner constructs new knowledge in a personal, idiosyncratic fashion, the best path through a textual resource may differ for each learner. "Active reading" is a term used to emphasize the dynamic, opportunistic processes observed in non-recreational reading of expository texts as done by experts and motivated readers. In Table 1 we list a number of active reading strategies culled from the literature, which we group into behavioral, cognitive, and metacognitive strategies (from Collins et al. 1989, Foltz 1996, Mannes & Kintsch 1987, O'hara 1996; Roast et al. 2002, Schilt et al. 1999). Johnson & Afflerback see reading comprehension skills as being "eminently teachable."

#### **Behavioral strategies**

- Skimming (for an overview or "forward planning")
- Scanning (to locate specific content)
- Reviewing (summarizing to identify main points)
- Bookending (looking at the beginning and end of a book or section)
- Big picturing (going to the table of contents for an overview of the structure)
- Deepening (diving deeper or obtaining additional information on a subject)
- Refocusing (on a different level of the text)
- Exploring (taking tangents not immediately related to a high priority goal)
- Writing (note taking, annotating, highlighting, etc.)

#### **Cognitive strategies**

- Summarizing & consolidating (identify main points)
- Connecting (creating meaning and relevance for new knowledge)
- Evaluating (critiquing and synthesizing)
- Questioning (determine what needs to be know, explained, or justified)
- Predicting (anticipating where the author is going)
- Planning (what pages to visit next)

#### **Metacognitive strategies**

- Monitoring coherence, understanding, effort, and efficiency
- Setting goal and managing goal priority
- Deciding which behavioral or cognitive strategy to use next

**Table 1:** Active Reading Strategies

The ability to effortlessly "jump" from one "place" in a text to another, via hyperlinks or text searching, leads to a wide array of potential benefits and new problems. Hyperbooks can contain alternative structures, content, and navigation paths that emphasize different goals, skill levels, or perspectives (Conklin 1987, Ferguson et al. 1992; Spiro & Jeng 1990; Cleary & Bareiss 1996). Learners have the ability to navigate through the content in ways that match their goals, interests, and learning styles. Yet the distinguishing characteristic of hypermedia, i.e. its easy random access, leads unavoidably to a set of problems, or "side effects": disorientation, poor narrative flow, poor conceptual flow, and cognitive overload (Conklin 1987, Lucklin et al. 1999, Beasley & Waugh 1995, Plowman et al. 1998, Stanton & Baber 1994). These issues are described in more detail in (Murray 2002, Murray in press). MetaLinks has several features, described later, that support learners'

exploration of hypermedia spaces while ameliorating these four classic problems.

Studies by Foltz (1996) indicate that users reading hypermedia documents are active opportunistic problems solvers who look for cues and navigate with a goal of maintaining semantic coherence. He identifies a number of comprehension issues in hypermedia that are related to the "side effects" mentioned above. A primary goal during reading is to maintain coherence. Hypermedia jumps can make it hard to maintain local coherence. These problems are exacerbated for readers who have inadequate preexisting conceptual structures into which to fit new knowledge. A primary goal during reading is to maintain coherence. Hypermedia jumps can make it hard to maintain local coherence. These problems are exacerbated for readers who have inadequate preexisting conceptual structures into which to fit new knowledge. Jacobson & Archodidou (2000) extend previous research in Cognitive Flexibility Theory (Jacobson & Spiro 1995) and assert that hypermedia texts should reify the deep structural and conceptual aspects of a domain. Research comparing expert and novice performance has shown that novices tend to focus on surface aspects and miss deep structure aspects of problems and examples (Chi et al. 1981). We believe that scaffolding that makes the deep structures and concepts of a domain explicit in a text could help novice learners.

### **The MetaLinks Adaptive Hypermedia System**

The MetaLinks software comprises an authoring tool and web server for adaptive hyperbooks (Murray and Murray et al. 1998, 2000, 2002). Adaptive hypermedia systems compose pages "on the fly" so that the content, style, and/or sequencing of the page is customized to the needs of the particular learner and situation (DeBra & Calvi 1998, Brusilovsky 1998, Spetch & Oppermann 1998). Though non-adaptive (static) hypermedia has been popular for over 20 years, it is only recently that internet data-base technologies that enable dynamic configuration and personalization of web pages have become common. This new features introduce both opportunities and new problems for readers, about which little research has been done.

Adaptivity and other MetaLinks features allow us to design and evaluate digital artifacts that serve multiple purposes. The same hyperbook can serve as textbook and reference book; can be equally appropriate for novice and advanced readers, and can be coherently read from a number of thematic perspectives. Figure 1 shows a typical MetaLinks hyperbook screen. From top to bottom, it contains the navigation bar, the page title, the page text, "custom depth control" navigation buttons, and a list of links to children pages. The author can include as many figures as desired, and specify a scaling factor for each picture. In addition to the main content window shown in the figure, there are separate windows for a table of contents, a search tool, a glossary, and an annotated history tool. Green colored underlined words correspond to words in the glossary. When the user drags the cursor over one of

these words its definition pops up as shown in Figure 1. When the user clicks on the "Related Information" tab, they see a list of links to related pages, as shown in the insert to the right of the figure. The user can navigate through the book hierarchically using parent, subtopic, and sibling topic links, and can navigate associatively, through the link list that pops out in the "Related Information" menu.

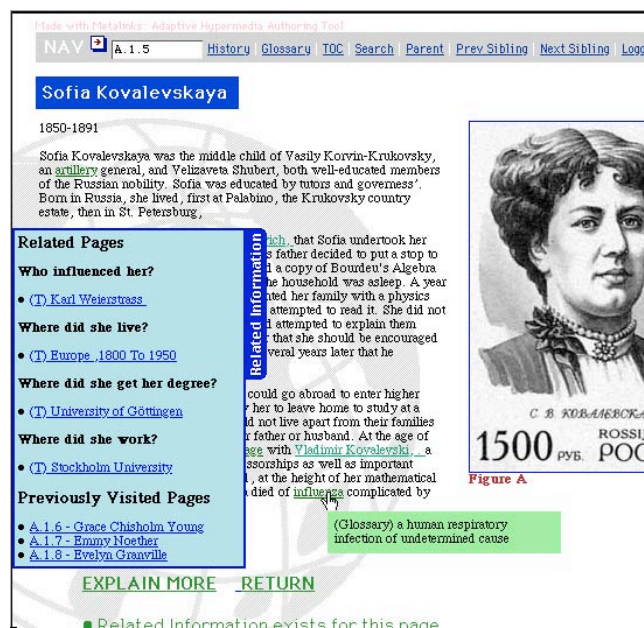


Figure 1: MetaLinks hyperbook as seen in a web browser

The system includes a sophisticated authoring tool that makes it easy to manage content, media (graphics, applets, etc.), and hyperlinks. The MetaLinks authoring tool and web server is built using a FileMaker Pro and JavaScript coding. All user behavior is recorded in a database, to allow for adaptivity and facilitate study data collection.

Most texts are structured and conceptualized in terms of three "epistemic forms" (Collins & Ferguson 1993): narrative, hierarchy, and network. Learning has traditionally been mediated by narrative (or episodic) structures such as spoken words and books (Luckin et al. 1988); cognition has hierarchical aspects (as indicated in most theories of cognition and problem solving (e.g. Ausubel 2000)); and memory and thought have associative or network aspects (Woods 1975). We have tried to design MetaLinks to support all three forms, while minimizing the potential cognitive tensions introduced in having three different but overlapping formats at once. Mannes & Kintch (1987) found that outlines *reflecting* (or consistent with) the thematic organization of the main text improved comprehension and verbatim recall. Such hierarchically consistent outlines are called "advanced organizers" (Ausubel 2000). Outlines that are organized in a thematically *different* way than the main text (thus giving a alternate or diverging perspectives on the material in a more associative fashion) encourage deeper processing and are better for problems solving, inferences, transfer, and

integrating new knowledge into existing knowledge. MetaLinks hyperbooks provide both thematically consistent (hierarchical) and thematically divergent linking.

Many MetaLinks features are slight modifications of techniques used in other systems, but three features are innovations that are more particular to MetaLinks: custom depth control, thematic links, and narrative smoothing. Custom depth control supports *hierarchical* conceptualizations of content; thematic links support *associative* conceptualizations of content; and narrative smoothing supports *narrative* coherence in reading. Below we describe these three features.

**Horizontal Reading and Custom Depth Control.** In MetaLinks hyperbooks the default narrative flow (a linear navigation path for which the reading or organization of the content is most natural or perspicuous) is organized for "horizontal reading." This differs from traditional books and most other hyperbooks. The default "next" page is the sibling page, so if one is reading the introduction to Chapter 3 the default next page is the introduction to Chapter 4, which is navigated to with the "Next" button. Thus the default is to continue reading at the same level of generality. This sets the stage for an innovation called "custom depth control." To the left of the Next button is the "Explain More" button. This button begins a path across the children of the current page (by pushing the children on a stack). When the last child in a sibling sequence is reached the Next button becomes a Return button, so that the user can easily return to the parent page where they originally pressed the Explain More button. Thus, the user has continuous control over the level of depth at which they are reading.

**Supporting thematic relationships.** Hierarchies do not capture the conceptual richness of most domains. There are multiple perspectives on the material, suggesting multiple learning paths. Each MetaLinks page has a set of thematic links (non-hierarchical, associative, or "tangential" links) to other pages, accessed via a pop-out menu by clicking on the "Related Information" tab (see Figure 1). Unlike most other hypermedia, the links are "typed" or categorized to indicate the type of relationship they represent. The authoring tool provides a list of possible link types, but the author can create her own types for each hyperbook. They allow the learner to maintain a path through the material that responds to their individual curiosity and inquiry goals. Thematic links are similar to those used in ASK systems (Ferguson et al. 1992) but in MetaLinks the link vocabulary is not fixed, it is determined by the subject matter expert.

**Narrative Smoothing.** As mentioned, the narrative of the hyperbook is written to flow most perspicuously for users using horizontal reading and custom depth control. If the reader navigates using any other feature, for example thematic links or the search engine, then the narrative would have a discontinuity. We have a simple but elegant adaptive solution to the narrative flow problem that we call "narrative smoothing." Each page has associated with it an "intro text" paragraph that eases the reader into the subject of the page,

giving a little background, context, or introduction. If the user jumps to that page in a non-standard way, i.e. one that does not follow horizontal reading, the intro-text is inserted before to the main text of the page (otherwise it is not included).

Below we describe how MetaLinks features relate to four important active reading and learning issues: coherence, reading strategies, background knowledge, and exploration.

**Supporting local and global coherence.** MetaLinks includes a number of features that support coherence in reading, and thus better comprehension. Features that support local coherence include narrative smoothing, inquisitory page titles in links, pop-up foot notes and glossary definitions (which alleviate the need to digress to another page to read a foot note or definition), and custom depth control (which allows reading or skimming at any level without interrupting the narrative). To support global coherence, MetaLinks has an annotated table of contents (TOC), visual content maps, a page numbering scheme that identifies a page's position in the hierarchy, and thematic links that reify the key thematic dimensions of a domain.

**Supporting active reading strategies.** In the move from text to hypertext, some issues are trivialized, some are problematized, and new issues are introduced. The basic features of MetaLinks hyperbooks practically trivialize the "behavioral" set of active reading strategies in Table 1. Skimming is directly supported with the horizontal reading feature. Scanning (looking for a specific thing) is done easily with the search engine. Reviewing involves returning to a previous page (a Back or Return button). Bookending in MetaLinks books is done automatically due to its rhetorical structure and custom depth control feature. Big picturing involves using the TOC tool. Deepening is supported directly with custom depth control. Exploring is supported with thematic links. The (non-behavioral) cognitive and metacognitive active reading strategies are, of course, less straightforward to support (and more difficult to measure in both texts and hyperbooks). But we believe that hyperbooks support these skills. Summarizing is supported through horizontal reading and the alternative rhetorical structure of our hyperbooks. Connecting is supported through the thematic links, which reify important connections and allow readers to learn about a connected topic as soon as they become aware of or interested in the connection. Evaluating/critiquing/synthesizing are also made easier when important relationships are made more explicit and easy to follow. Questioning, predicting, and all of the other cognitive active reading strategies are supported to the extent that local and global coherence are supported (as described above). When reading is more coherent it consumes less cognitive resources, and these resources are freed up for higher level processes such as critiquing, synthesizing, etc. The same holds for supporting metacognitive strategies, which are more difficult to use when cognitive resources are consumed by lower level processing.

**Accounting for background knowledge and prerequisites.** As mentioned above, background knowledge has a significant impact on learning, coherence, navigation, comprehension, and strategies. The MetaLinks system includes several features that allow readers with multiple levels of expertise to use the text, and it allows readers with low expertise or missing prerequisite knowledge to learn what they need to learn. Skimming in the Custom Depth feature allows readers to read at a level of depth and detail that fits their prior knowledge. Thematic links can be used to create "prerequisite" links between pages, making it explicit to readers what material should come first, and whether or not they have read this material (the color of the link text shows if they have been there). The glossary pop up feature assists the reader in filling in small gaps in knowledge. The Glossary Base Page feature allows easy access to additional information.

**Supporting exploratory navigation.** Above we identified exploration as one of the strategies used in active reading. Though most hypermedia projects focus on goal-directed learning and information finding tasks, it has been our intention to also support behavior that has been called inquiry-based, discovery-based, or exploratory. Many learning tasks involve an initial convergent stage of articulating and refining the goal or question and then divergently exploring potential sources of information before returning to convergent thinking and focused search (Wallace et al. 2000). Exploratory navigation is particularly appropriate for open-ended questions and/or learning in ill-structured domains in which the richness of the content suggests multiple themes or perspectives (McAleese 1989, Heller 1990, Spiro & Jehng 1990). MetaLinks supports exploratory and curiosity-driven behavior in several ways. Thematic links and inquisitory page titles facilitate exploring related but tangential topics. Custom depth control and glossary base pages makes it easy for the reader to "dive deeper" into topics she is curious about. Finally, to the degree that many features minimize hypermedia "side effects" they make it easier to explore tangents while maintaining coherence and orientation.

## Results of Evaluations

To date, MetaLinks has been used to author four hyperbooks. The largest is the introductory geology hyperbook *Tectonica Interactive*, which has approximately 400 pages, 500 graphics and 320 glossary entries (from Thompson & Turk 1997). We have conducted three formative studies of the MetaLinks software using *Tectonica Interactive* in clinical settings. All were done with college aged students, and there were 5, 19, and 24 subjects, respectively, in the three studies. Each study collected data from automatic tracking of navigation, questionnaires of approximately 50-items, focus group interviews, and semi-structured interviews. The results (see Murray 2002) are summarized as follows:

- Subjects overwhelmingly reported high levels of usability and perceived learning effectiveness (in

general and on each feature and tool). There were no significant effects of gender, computer familiarity, prior knowledge of geology, or preference for Geology on questionnaire responses, tool use, or navigation behavior.

- Subjects demonstrated many navigation styles, and a wide range of tool preferences. This reflects the variety of reading strategies seen in the text comprehension literature, and supports the existence of our variety of navigation tools. Both focused and exploratory behavior were observed, supporting our hypothesis that the tools support a range of learning tasks and goals.
- Using "ablation studies" and multiple versions of the software we tried (in study #3) to focus on the effects of the narrative smoothing and related links features. We found no significant effects from the use or existence of these features, but these results were limited by ceiling effects and the following findings.
- The custom depth feature was highly used and significantly correlated to user satisfaction. The related links were not used very often (1-5% of moves vs. 10-15% for children links and custom depth control links.) In one ablation study we demonstrated that feature salience had a significant effect on the use of this feature. The feature was used more when it was shown on the page and did not require the user to click the pop-out tab.

Our evaluations thus far have tested the overall usability and usefulness of MetaLinks features. Our next steps will be to monitor specific active reading strategies, and analyze how these relate to session, subject matter, and reader characteristics.

### Future Directions

In the future we plan to conduct additional investigations to: 1) push the tasks and content to more difficult levels; 2) measure learning effects (we only had user reports of usability, usefulness, and learning in previous studies--we did not measure geology knowledge changes), 3) try more domains to test the generality of the approach; 4) example the use of active reading strategies; 5) study the authoring process; and 6) develop and test hyperbooks in actual classroom situations.

### Acknowledgements

Most of the work reported here took place at the University of Massachusetts Computer Science Department in, Amherst, MA, with the help of: Professor Chris Condit, Janette Piemonte Gartner, Tina Shen, Jason Thibedeau, Erik Haugsjaa, Dr. Phil Kelleher, and Samia Khan. This material is based upon work supported by the National Science foundation's under Grant No. NSF DUE-9652993, and by the Office of Naval Research AASERT grant no. ONR/N00014-97-1-0815. Disclaimer: Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not

necessarily reflect the views of the Nation Science Foundation or the Office of Naval Research.

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