Content design issues in adaptive hyperbooks

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Abstract: We explore the design issues of adaptive hyperbooks in relation to how using hypermedia technology changes the nature of the traditional book. To address some of these issues we have developed and tested MetaLinks, an authoring tool and web server for adaptive hyperbooks. The system is designed to: 1) support inquiry, exploratory, or curiosity-driven learning in richly interconnected material; 2) support the construction and conceptualisation of content through three 'epistemic' forms: narrative, network and hierarchy and 3) ameliorate a number of usability issues: disorientation, cognitive overload, poor narrative flow and poor conceptual flow. These goals are achieved through a number of interface and adaptive features, including 'narrative smoothing,' 'custom depth control,' and 'thematic links.'

Keywords: adaptive hypermedia; hyperbook; knowledge-based educational software.

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Biographical notes: Dr. Murray has been researching, publishing, consulting, and leading workshops in various aspects of advanced educational technology and cognitive tools since 1985. Areas of interest and expertise include authoring tools, knowledge engineering, inquiry learning environments, and discourse ethics, as they apply to computer-supported learning and collaboration. He has directed a number of educational software projects in industry and in university/college research contexts. His research projects include MetaLinks (adaptive hyperbooks), Eon (ITS authoring tools), SimForest (glass box simulation based learning environments for inquiry learning), RASHI (tools scaffolding inquiry learning), and Perspegrity (collaborative software supporting integrity and perspective in publication, dialog, and communication). Other areas of interest and publication include process-based learning metrics (ZPD), ITS ontologies, ITS interoperability and reusability, teacher professional development, distributed models of curriculum, software evaluation methods, example-based strategies for teaching concepts, and the representation of instructional strategies. In addition to research activities Murray teaches graduate and undergraduate courses at Hampshire College and the University of Massachusetts.

1 Introduction

Innovations in digital media and hypermedia have extended the possibilities inherent to our notion of and use of the book. For our purposes, 'hyperbooks' are similar to traditional textbooks but modified and extended according to the affordances of the web and hypermedia [1]. Though we are dealing with hyperbooks on the web, many educational CD-ROMs and websites are hyperbooks under our definition. The key differences between traditional books and hyperbooks are the decomposition of the material into modular pages, the inclusion of hyperlinks and the addition of interactive tools such as search engines [2]. *Adaptive* hypermedia documents are composed 'on the fly' so that the content, style and/or sequencing of the page is customised to the needs of the particular learner and situation [3,4]. Though non-adaptive hypermedia books have been designed and studied for about 30 years [5] it is only recently that internet database technologies that support the dynamic configuration and personalisation of web pages have become common. This advance has allowed technologies and approaches developed for intelligent tutoring systems to migrate to the field of educational hypermedia resulting in adaptive hyperbooks [3]. These new technologies have a better chance to address the needs of active reading and learning. Learning and information gathering are opportunistic, dynamic processes. Because learners have different background knowledge, learning styles and goals and because each learner constructs new knowledge in a very personal, idiosyncratic fashion, the best path through a text-like resource may differ for each learner. Active learners and readers make moment-to-moment decisions about the depth and focus of their inquiry. They use metacognitive skills to decide when to skim, look ahead, summarise, evaluate, go back to learn prerequisite content and go on exploratory tangents [6–8].

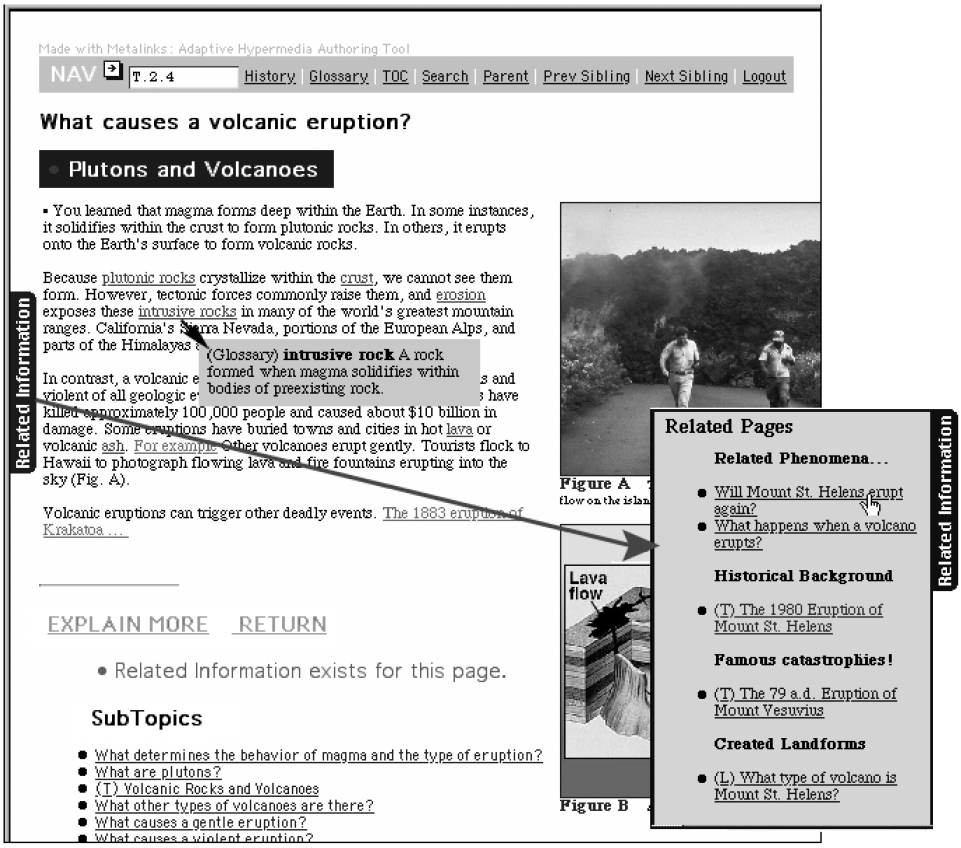
In the transition from traditional books to hyperbooks, we must reinterpret the form and function of the page as the page moves to the computer screen. The flow of experience of reading is transformed as it includes navigating. Our understanding of a book's content is altered when digital books can be composed or adapted dynamically for each use. The changes are significant from both the author's and reader's (user's) perspectives. Adaptive Hyperbooks are fairly recent phenomena and there have been very few studies investigating key design issues [9,10]. To address some of these issues we have developed and tested MetaLinks, an authoring tool and web server for adaptive hyperbooks. In what follows, we will describe MetaLinks and discuss a number of key issues in the transition from traditional books to hyperbooks. In parallel with these general hyperbook issues we will describe the particular approach that we took with the MetaLinks project.

2 The MetaLinks user interface

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's 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 coloured underlined words correspond to words in the glossary. When the user 'mouses' over these words the definition pops up

('stretch text'), as shown in the figure. Teal coloured underlined words indicate footnotes, which also pop up as stretch text. 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.

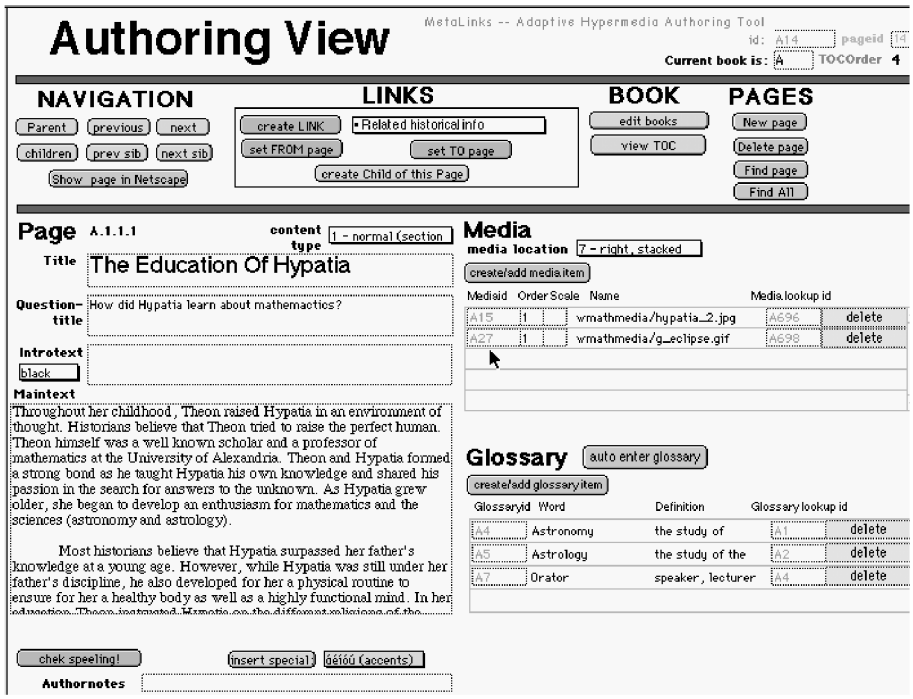
Figure 1 Tectonica Interactive page T.2.4, with a picture showing two geologists running from a lava flow



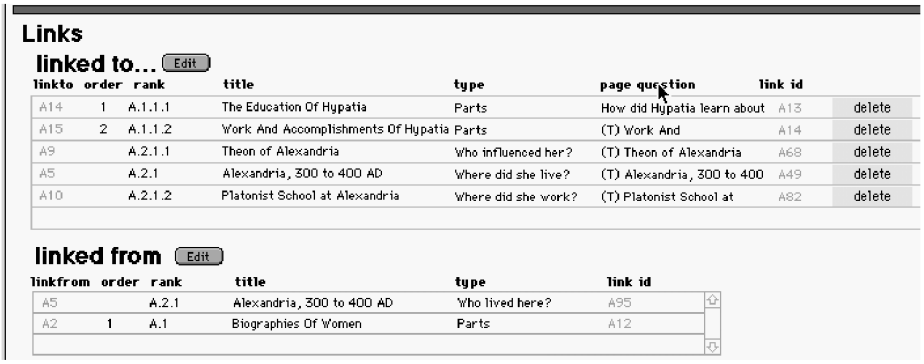
To date, MetaLinks has been used to author four hyperbooks (see http://ddc.hampshire.edu/metalinks/). The largest is the introductory geology hyperbook Tectonica Interactive with approximately 400 pages, 500 graphics and 320 glossary entries. The second MetaLinks hyperbook authored was the MetaLinks Users Guide. The remaining two hyperbooks were created as part of a Hampshire College service learning class. College students in the class used MetaLinks to build hyperbooks in collaboration with two community based organisations. The first was 'Famous Women Mathematicians' which was built in collaboration with Amherst Middle School teachers, for use by an eighth grade class. The second was 'Early 20th Century Children's Games', a hyperbook built in collaboration with a group of senior citizens enrolled in a computer literacy class in Holyoke Massachusetts. The project became somewhat of an oral history project, as seniors told us their memories of the games they played as children and we organised this material thematically for the hyperbook. Both these college–class-built hyperbooks are of the order of 30–50 pagesin extent.

The system includes a sophisticated authoring tool that makes it easy to manage content, media (graphics, applets, etc.) and hyperlinks. The MetaLinks authoring tool is built using a FileMaker Pro database and web server and JavaScript coding. The system has separate databases for pages (text content), page links, glossary items, media and user data. All user navigation moves and tool uses are recorded in the User database. The Media database can include images, movies, applets and entire external HTML files (this last feature is used to include tables in a hyperbook). Figure 2 shows the main window of the authoring tool, showing content for the 'Famous Women Mathematicians' hyperbook.

Figure 2 (A) MetaLinks authoring tool, top section; content for the 'Famous Women Mathematicians' hyperbook (B) MetaLinks authoring tool, bottom section



(A)



(B)

3 Hyperbook design issues and MetaLinks solutions

A number of benefits of hyperbooks have been proposed. Hyperbooks can contain alternative structures, content and navigation paths that emphasise different goals, skill levels or perspectives [1,11,12]. Learners have the ability to navigate through the content in ways that match their goals, interests and learning styles. The learning experience can be more learner-centred and interactive, as learners actively create their learning trajectories in ways not easily done with traditional books [13]. How do hyperbooks compare to other forms of educational software? Hyperbooks *could* contain features such as interactive exercises, simulations, user scoring and coaching found in other types of educational systems, but these are peripheral to the essential nature of the hyperbook. Though simulated tasks and feedback are important aspects of advanced educational software, our discussion is concerned with the reading, searching and browsing activities that take place while learning with hyperbooks. While reading and browsing seem mundane activities when compared to the possibilities inherent to computer-based learning environments, there are important research issues related to these limited activities. We discuss below a series of issues that are inevitably encountered in moving from traditional books to hyperbooks (and adaptive hyperbooks). Adaptive hyperbooks are a new form of text with unique possibilities and problematic issues for the author and the user, which the research community has only just begun to explore. The fundamental difference between (adaptive) hyperbooks and paper-bound books is illustrated by the list of design issues we will address in relation to the MetaLinks project:

- modularity of pages
- limiting how much content is on the page
- rhetorical and hierarchical structure
- supporting thematic relationships among content
- combining text book and reference book
- hypermedia side effects:
  - dealing with disorientation
  - dealing with poor narrative flow
  - dealing with poor conceptual flow
  - dealing with cognitive overload
- supporting exploratory navigation
- supporting multiple epistemic forms
- link and content adaptivity.

3.1 Modularity of pages

The experience of reading and navigating among hyperbook pages (or web pages) can be quite unlike that of flipping through the pages of a text book. Unlike textbooks, in which page breaks are of little significance and topics are organised around sections, the pages in hyperbooks are relatively modular content units. Some hypermedia documents have

long pages with lots of content that must be scrolled down, but such pages cannot be used as flexibly. Traditionally, hypermedia is defined as being composed of 'nodes' (called pages in our case) and navigable 'links' between these nodes [1]. The pages are not completely independent, but usability concerns compel us to organise the material into small grain-sized thematic units to allow for non-linear navigation, multiple perspectives and multiple uses. That is, a modular page that covers one or a small number of tightly related topics is more able to function as a component in multiple reading trajectories with different purposes.

MetaLinks approach: In MetaLinks books we conform closely to the modularity criterion. Also, in most hypermedia a link goes from a particular phrase (the underlined text) to another page (or location within a page). MetaLinks hyperbooks links go from *page* to page. We see the page as a thematic unit and the 'related links' (described later) are semantic relationships between these units.

3.2 Limiting how much content is on the page

It is best to limit the amount of text on each hyperbook page. This is in part due to the modularity criterion and also because commonly accepted hypermedia usability guidelines recommend a limited amount of content on each page (in part because reading computer screens involves more eye strain). Users also expect a greater proportion of pictures to text in hypermedia vs. traditional text books.

MetaLinks approach: Our policy for nominal page size is not precise, but supports the goal of being able to navigate to a particular page (as opposed to navigation to somewhere *within* a page) to learn about a particular topic. In general, we aim for pages being two to four paragraphs long. Non-essential text and graphics such as examples and footnotes can be hidden inside 'stretch text' (or stretch pictures), as shown in the figure. Stretch text allows the screen to be less cluttered while still giving the user easy access to additional information.

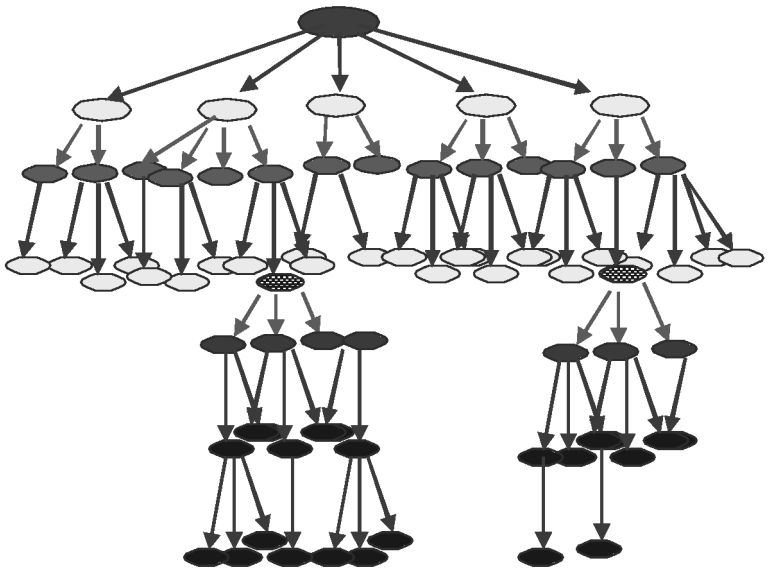
3.3 Rhetorical and hierarchical structure

Some hypermedia documents have a completely open network-like structure. But for hyper*books* it is best to maintain the hierarchy (as reified by the table of contents (TOC)) as the primary organisational structure (for reasons described below, under 'epistemic forms'). We believe that completely unstructured or spaghetti-linked content has poor usability and that the link structure of a hyperbook's content should reflect and reify the knowledge structure of the domain [14–16]. MetaLinks hyperbooks have a primary hierarchical structure defined with 'parent/child' links and an additional network-like structure defined using 'thematic links' (i.e. 'related information links'). The limitations of imposing a single primary hierarchical structure are outweighed by the usability and navigation benefits of making each page have a natural home with parent, child and sibling relationships that specify key subordinate/super-ordinate content relationships. (A family tree metaphor, 'parent/children/sibling.' is used for hierarchical relationships among pages in MetaLinks). Traditional textbooks are constrained by convention to having consistency in the size and depth of each chapter or section, but with the advent of electronic books we are no longer subject to these constraints. The author may decide to expand one particular section into what might be considered an entire 'book' in the traditional sense. The user reading any page (or at any level of generality) need not know

how 'deep' the book goes with that topic. Also, the author who wants to leave open the option of expanding sections in the future can write the text of a page in such a way that it does not presuppose the depth of content below the page.

MetaLinks approach: Most books are structured around a chapter/section/subsection decomposition model. In MetaLinks hyperbooks the parent/child relationship is used to create a hierarchical decomposition. We do not call parts chapters or sections because the hierarchy can go arbitrarily deep and different users may have 'top level' entry points that vary in how deep they are in the hyperbook. The hierarchical structure of the book is reified in the annotated TOC tool. The rhetorical structure of most books includes transitional elements that introduce, conclude, or relate sections. In MetaLinks hyperbooks a parent page is considered a summary, overview, or introduction to all of its children pages (unless the page has no children). Think of everything in the family tree 'below' a page as containing further details or elaborations of that page. After reading a page, the users decides whether they want more depth on that topic or want to continue reading at the same depth (see 'horizontal reading' and 'custom depth control' below). If they navigate to more depth, eventually they will 'pop back up' to the original page. To maintain a sense of orientation they are given a visual indication that they have returned to a page from where they previously branched off. According to this temporal flow of events, the original page becomes both an introduction and a conclusion for its children. Thus, the author is encouraged to compose a page so that it works as both a summary and a refresher to its children's contents. Figure 3 shows a hypothetical book hierarchy. The top half of the figure illustrates the typically uniform structure of traditional books. The bottom half illustrates the significant expansion of two topics, which is straightforward in MetaLinks hyperbooks but in a traditional book would result in a confusingly lopsided text and a book that was twice as heavy to carry.

Figure 3 Sample content hierarchy



3.4 Supporting thematic relationships among content

As mentioned, the primary organisational structure for hyperbooks is the hierarchy. However, hierarchies do not capture the conceptual richness of most domains. Each topic is related to others in numerous ways. There are multiple perspectives on the material, suggesting multiple learning paths. Hyperlinks in hypermedia support this more associative and flexible aspect.

MetaLinks approach: MetaLinks includes *thematic links* (non-hierarchical, associative, or 'tangential' links) called Related Links in addition to the hierarchical child and parent links between pages. Each page has a set of Related Links to other pages, accessed via a pop-out menu by clicking on the 'Related Information' tab in Figure 1. Unlike most other hypermedia, the links are 'typed' or categorised 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 curiosity and inquiry goals. Here are some of the approximately 20 link types we used in the geology domain: 'Where in the world?' 'Are scientists sure?' 'Extreme cases and famous catastrophes.' 'Geologists used to think …' 'How is it measured?' 'What do I need to know first?' Authors can use the link types to organise their content creation. Thematic links encourage the learner to assimilate domain knowledge structures that reflect the relationships and themes important to the author/expert. Link types can also act as author prompts that remind or inspire the creation of related content or the creation of more links among existing content. For example, the existence of a link type called 'alternate theories' not only helps the author organise the database of knowledge, but may inspire her/she to author something about alternate theories to a page when he/she may not otherwise have thought to do so. Link types called 'Pros' and 'Cons' can scaffold content organisation along the lines of alternative viewpoints. Using typed links that structure the information space according to a fixed set of common issues, questions or themes, similar to that used in ASK systems [11,17], such conceptual structuring of the information space aids both user and author in creating a mental model of the semantic space with appropriate expectations for how things can be related. Thematic links provide more textual 'coherence' [7]. Coherence (the amount of interrelatedness of the text's propositions) has been shown to improve comprehension in reading traditional texts.

3.5 Combining textbook and reference book

Since hyperlinks and search engines support flexible navigation for multiple reading purposes, the author has reason to structure the book more like a reference book, resulting in a form that is in between textbooks and reference books. Coordinated use of the hierarchical and thematic links in MetaLinks documents allows authors to create books that serve these multiple purposes.

MetaLinks example: For example, in one student's authoring of a small hyperbook about a pop music group, she started by organising the entire book as a chronological story, including sections about hit albums, awards given and relationships to other musical groups as sub sections within the chapters for each year. This initial organisation was similar to what she had seen in other books. This book made it easy for readers interested in the group's chronology, but it was not well organised for readers interested in other themes, such as song lyrics or relationships to other bands. In the end she

reorganised the book to have separate chapters on lyrics, band history, awards and other rock bands, taking better advantage of the medium and making the book more reference-like. The primary chapter was chronologically based, but when the story came to a place where song lyrics, awards, or other bands were mentioned, then thematic links were provided to get more detailed information from other chapters. Similarly, in the chapter on lyrics, there was a link from a song to the page in the chronology chapter that discussed the events of the year in which the song was released. The entire book, with its several chapters each focusing on a different perspective, would not work well as a traditional book to be read front to back. But it did work as a hyperbook where the reader can focus on the narrative of the chapter that matches the theme of their curiosity and take tangents to other chapters as needed.

3.6 Hypermedia side effects

The distinguishing characteristic of hypermedia, i.e. the ability to navigate (or 'jump') easily from one location to another, in addition to being responsible for its benefits, leads unavoidably to a set of problems: disorientation, poor narrative flow and poor conceptual flow, cognitive overload [1,9,18]. These problems can also be seen as a result of the tension between the linear/narrative and non-linear/associative natures of hyperbooks. *Disorientation* refers to users not knowing where they are, where they have been, or how to get to where they want to go in hypermedia space (the 'lost in hyperspace' problem). *Narrative flow* refers to the didactic or rhetorical flow of the text itself. *Conceptual flow* refers to the flow of ideas or concepts. To clarify the difference, one could imagine a text with a good conceptual flow but which was poorly written and choppy, thus having poor narrative flow. Similarly, one could imagine text that seemed to read very smoothly but did not make rational sense, or in which prerequisite concepts were not introduced sufficiently for understanding the text and thus the text has poor conceptual flow. Good conceptual flow includes 'content readiness', which is the traditional intelligent tutoring systems goal of tailoring content so that the learner is neither bored because it is too easy, nor overwhelmed because it is too difficult (i.e. remaining within the learner's 'zone of proximal development' – see [19,20]). *Cognitive overload* refers to users being overwhelmed or confused by the options available to them in multi-path, multi-tool environments such as hyperbooks.

MetaLinks approach: Our goal is to support learners' exploration of hypermedia spaces while avoiding or ameliorating these four classic problems. Below, we describe our approach to each of these issues.

3.7 Dealing with disorientation

Hypermedia users need navigation support from both local and global perspectives. Globally, they need to be able to see 'the big picture' of the book and be able to know where the current page is in relation to this big picture. Locally, they need to be able to navigate to and have information about pages that are adjacent to or near the current page. Also, users need support with the temporal form of disorientation, i.e. 'where have I been?'

MetaLinks approach: MetaLinks has a number of features, including the table of contents and navigation bar, which support global and local orientation. The annotated history tool gives the user a picture of where they have been and importantly, shows *why*

they went to each page (whether from a search, a particular thematic link, etc.). The tool helps the user see the structure of their navigation path, where they took tangents, etc.

3.8 Dealing with poor narrative flow

As mentioned, the user's expectations for smooth narrative flow can be thwarted as they jump from page to page in hypermedia. There are local and global (structural) aspects to narrative. Previous work [18,21,22] focuses on maintaining a global narrative structure in hypermedia. This is to maintain a coherent thread of meaning from beginning to end, where all details can be seen in relation to the main ideas of the document. We would like our hyperbooks to be usable for diverse learning goals and thematic threads, so we do not try to maintain a single global narrative structure. Rather, we focus on the local flow of narrative from page to page. A smoother local flow of text, where the context of sentences and their relationship to other material is made explicit, enhances comprehension [7].

MetaLinks approach: In MetaLinks hyperbooks the default narrative flow (a linear navigation path for which the reading or organisation of the content is most natural or perspicuous) differs from text books and most other hyperbooks – it is breadth-first rather than depth-first and organised for '*horizontal reading*'. The default 'next' page is the sibling page. Thus, the default is to continue reading at the same level of generality. The children of any page cover the material at greater depth. In transforming a traditional text to the Tectonica hyperbook, we had to rewrite the text to conform to horizontal reading. We have a simple but elegant partial solution to the narrative flow problem, which we call '*narrative smoothing*'. Each page has associated with it an 'intro text' paragraph. This paragraph eases the reader into the subject of the page, giving a little background 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 pre-pended to the main text of the page.

3.9 Dealing with poor conceptual flow

Hyperlink jumps can also cause problems with the flow of ideas and the expectation that prerequisite information will come first.

MetaLinks approach: The glossary stretch-text partially addresses the conceptual flow issue. If learners do not understand a term they can easily see its definition. However, the terse definitions that pop up may not be enough. If the user *clicks* on a glossary term they navigate to its 'base page', which is the page in the hyperbook that best explains that concept. From a base page the user can navigate down to additional detail if needed. Also, the author can create related links of the type 'prerequisite concepts' for better content readiness.

3.10 Dealing with cognitive overload

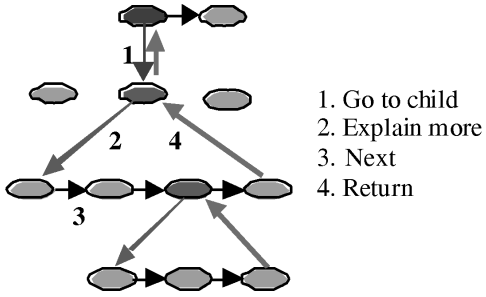
There will always be tradeoffs involved between the desire for an easy to use hypermedia system and a full-featured hypermedia system. However, with good interface design it is possible to have a usable and full-featured system.

MetaLinks approach: Feedback from users has informed MetaLinks' interface design. Cognitive overload from the variety of navigational features has not been seen as a

problem in recent formative trials. Stretch text can be used to limit the amount of text on the page, further reducing cognitive load. Horizontal reading sets the stage for an innovation called '*custom depth control*' which further addresses the problem of cognitive overload. In MetaLinks the Next and Back buttons in traditional hyperbooks are replaced with Explain More and Next buttons. 'Next' goes to the next page which continues at the same level of generality (horizontal reading). 'Explain More' begins a path across the children of the current page. When the last child in a sibling sequence is reached the Next button becomes a Return button and the user is returned 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 through the use of only two buttons.

For example, Figure 4 shows a path in which a user does the following: upon reading a page, they become interested in a particular subtopic as seen in the children links and then click on that child page (1). In reading that page they become interested in even more detail on that subject and press 'Explain more' (2). They begin a traversal across sibling pages using the Next button (3). They become particularly interested in the third sibling page and press 'Explain more' a second time for more depth on *that* topic. The Next button changes to a Return button when they reach the last sibling and they are eventually led back to where they began and can continue on from there. The adaptive buttons are one of the features that help users take reading discursions while maintaining orientation.

Figure 4 Custom depth control



3.11 Supporting exploratory navigation

The network, hierarchical and reference natures of hyperbooks facilitate more research-like and open-ended uses. Hypermedia supports behaviour called inquiry-based, discovery, or exploratory, which is particularly appropriate for open-ended questions and/or learning in ill-structured domains in which the richness of the content suggests multiple themes, perspectives, or learning paths [23,24]. MetaLinks contains features that support both open-ended and focused activity, but our work differs from other adaptive hypermedia projects in its greater emphasis on the support of behaviour called inquiry-based, discovery or exploratory (or divergent). Exploratory navigation is appropriate for open-ended questions and/or learning in ill-structured domains in which the richness of the content suggests multiple themes, perspectives, or learning paths [12]. Also, inquiry-based learning methods involve initial stages of articulating and refining

the driving question and then exploring potential sources of information before focusing on an information search [25].

MetaLinks approach: MetaLinks has integrated glossary and search tools to support inquiry. It facilitates exploratory and inquiry navigation behaviour in several other ways. First, the related links feature facilitates exploring related but tangential topics. Second, custom depth allows the user to read the material at their chosen depth level and easily explore any topic more deeply. Third, 'inquisitory page titles' (see Figure 1) express page relationships in terms of questions to support an inquisitory 'Q&A' navigation style (similar to ASK systems [11]). Finally, to the degree that the design of the child links, search and TOC features alleviate the four navigational 'side effects', the software supports the user in branching out from the default navigation path and maintaining orientation and flow [26].

3.12 Supporting multiple epistemic forms

Most hyperbooks are structured according to three ubiquitous forms, simultaneously: narrative, network and hierarchy. In addition to being common general organising structures, these forms are seen throughout the literature in cognition and software design as organising forms for memory and thought and as organising forms for the design of content and software artefacts. Collins and Ferguson [27] call such recurring forms 'epistemic forms' because they act as templates (and their associated 'epistemic games' act as procedures) that can guide and scaffold the construction of new knowledge. In our context these forms guide both the design of educational material and the learning that subsequently takes place. Each form has an important function. Reading and learning are linear activities, as is the flow of experience and conscious thought. Learning has traditionally been mediated by *narrative* (or episodic) structures such as spoken words and books and we have deep cognitive expectations about narrative continuity and structure in the learning process [18, p.1]. In addition to its narrative and linear aspects, cognition also has non-linear *network-like* aspects. Many aspects of memory, learning and thinking are 'random access', and associative, as in semantic networks [28]. Finally, cognition also has *hierarchical* aspects. For example, Ausebel's subsumption theory of meaningful learning includes content sequencing principles that capitalise on the specialisation and generalisation relationships that naturally exist between concepts [29]. The interplay between these three epistemic forms provides a tension from both the designer's and the user's perspective. Supporting these forms involves design tradeoffs such that it does not seem possible to maximise the environment for all three at once. For example, increasing the ease of associative navigation tends to decrease readability in the narrative linear sense. MetaLinks user feedback about usability suggests that we have found a reasonable balance of features supporting all three forms.

MetaLinks approach: MetaLinks supports narrative, network and hierarchy forms from both the authoring and the user perspectives. Authors make use of all three forms in composition and presentation and learners can make use of all three forms in learning and inquiry. The TOC and local navigation tools support the hierarchical structure. Thematic navigation links connect pages as in a semantic network, allowing for associative navigation. The search tool also supports associative navigation. Finally, custom depth control, horizontal reading and narrative smoothing facilitate the narrative aspects of learning.

3.13 Link and content adaptivity

Both the potential benefits and the known difficulties with hyperbooks have led researchers to implement a number of adaptive and intelligent software features [4,30,31]. Using knowledge-based representation methods the content, style and hyperlinking in a hyperbook can be adapted dynamically to the user, content type, or navigation history. Empirical evidence informing the design of such software is sparse, leaving open the question of how much additional effectiveness results from a given infusion of technological power (which adds significantly to the development cost and complexity of the software). Our approach has been to phase in feature implementation based on feedback from formative evaluations, including more sophistication in accordance with user needs. We would like to leave the locus of control and locus of intelligence with the user as much as possible.

MetaLinks approach: Several MetaLinks features involve adaptivity, using methods known as adaptive link annotation and adaptive content. The TOC is annotated to show which pages have been visited. The narrative smoothing feature adds the introductory paragraph to pages conditioned upon whether the navigation path was 'horizontal'. On the main page a mark appears next to the page title indicating whether the user has previously seen that page. The function and availability of the Explain More, Next and Return buttons changes based on whether the user chooses custom depth control or jumps to a tangential page. Page links are shown using the page title or the 'question title', based on the type of link. If applicable 'Related links exist for this page' is inserted on the page to encourage users to inspect the pop-out menu on pages that have related links. The links in the annotated history page are annotated with the link types, or 'reasons' why the page was visited. We have also implemented a perquisite overlay structure, using the glossary terms as a concept map. Our intention was to use this to indicate 'learned' and 'ready to learn' pages as in the InterBook system [4]. But we felt that just the page visitation data (our system does not yet include quizzes or interrogative interactions) was insufficient to infer concept knowledge and we are looking for evidence to support the need for this feature.

4 Conclusions and discussion

MetaLinks is designed with three primary goals. The first is to support inquiry, exploratory, or curiosity-driven learning (all meaning more or less the same thing) in richly interconnected content. The second, related goal, is to support the construction and conceptualisation of content through three 'epistemic' forms: narrative, network and hierarchy. The third goal is to ameliorate a number of usability issues: disorientation, cognitive overload, poor narrative flow and poor conceptual flow, that inevitably arise with hypermedia documents. MetaLinks includes variations of features found in other adaptive hypermedia systems. We have given more detailed descriptions of those features that are relatively unique or innovative, including narrative smoothing, custom depth control and thematic links. In other papers we discuss evaluation trials, the specifics of the adaptive features and compare this work with other hypermedia and adaptive hypermedia projects. In this paper we compared the authoring and use of hyperbooks with traditional books, outlined a series of ubiquitous issues in hypermedia and hyperbooks and described the MetaLinks approach to these issues.

We conducted two formative evaluations of Tectonica, which are the focus of references [32,33], one with 20 subjects, the other with 24. The empirical evidence from both trials indicates that the current set of features, which leave the locus of control and intelligence solidly with the student, in general avoid all these potential problem issues of disorientation, cognitive overload, discontinuous flow (poor narrative flow or poor conceptual flow) and content non-readiness (these terms are described later). Overall satisfaction and perceived learning effectiveness were high, as subjects responded positively to questions regarding usability and usefulness. For example, in the first study 90% said they would prefer using the hyperbook to a text book. No individual feature stood out as being confusing. We also noted that there was a wide range of navigation styles and tool use among subjects. Subjects indicated that they explored topics unrelated to their initial question and that the software facilitated exploring according to curiosity or interest (but there was only suggestive evidence for attributing this to specific features). In the first study the Go To Child navigation tool was used most often and in the second the Custom Depth Control tool was used most often (we do not have a satisfactory hypothesis concerning the difference). The Related Links feature was underutilised in both studies and we plan to investigate why this was so in future studies [34].

Our future plans include studying the active reading processes in adaptive hyperbooks of several diverse domains and identifying how user goals and styles affect the way in which they use navigation tools and studying the authoring process in several domains to determine how our current representational framework and features differentially support different content types and teaching strategies (such as spiral teaching).

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References and Notes

1 Conklin, J. (1987) 'Hypertext: an introduction and survey', *IEEE Computer*, September, pp.17–41.

2 We acknowledge that in moving from paper to screen many affordances are lost. And, though our intent is not to proclaim the benefits of electronic books over traditional books, we do not discuss the relative advantages of paper books in this paper.

3 Brusilovsky, P. (1998) 'Methods and techniques of adaptive hypermedia', in Brusilovsky, P., Kobsa, A. and Vassileva, J. (Eds.): *Adaptive Hypertext and Hypermedia*, Kluwer Academic Publishers, The Netherlands, Chap. 1, pp.1–44.

4 Brusilovsky, P., Schwartz, E. and Weber, G. (1996) 'A tool for developing adaptive electronic textbooks on the WWW', *Proc. of WebNet-96*, AACE.

5 Nelson, T.H. (1980) *Literary Machines*, Mindful Press, Sausalito, CA.

6 Collins, A., Brown, J.S. and Newman, S. (1989) 'Cognitive apprenticeship: teaching the craft of reading, writing and mathematics', in Resnick (Ed.): *Cognition and Instruction: Issues and Agenda*, Lawrence Erlbaum, Hillsdale, NJ.

7 Foltz, P.W. (1996) 'Comprehension, coherence and strategies in hypertext and linear text', in Rouet, Levonen, Dillon and Spiro (Eds.): *Hypertext and Cognition*, Lawrence Erlbaum, Hillsdale, NJ.

8 Mannes, S. and Kintsch, W. (1987) 'Knowledge organization and text organization', *Cognition and Instruction*, Vol. 4, No. 2, pp.91–115.

9 Dillon, A. and Gabbard, R. (1998) 'Hypermedia as an educational technology: a review of the quantitative research literature on learner comprehension, control and style', *Review of Educational Research*, Vol. 68. No. 3, pp.322–349.

10 Eklund, J. and Brusulovsky, P. (1998) 'The value of adaptivity in hypermedia leaning environment: a short review of empirical evidence', *Proceedings of the 2nd Workshop on Adaptive Hypertext and Hypermedia: Hypertext '98*, Pittsburgh, June.

11 Ferguson, W., Bareiss, R., Birnbaum, L. and Osgood, R. (1992) 'ASK Systems: an approach to the realization of story-based teachers', *J. of the Learning Sciences*, Vol. 2, No. 1, pp.95–134.

12 Spiro, R.J. and Jehng, J.C. (1990) 'Cognitive flexibility and hypertext: theory and technology for the nonlinear and multidimensional traversal of complex subject matter', in Nix, D. and Sprio, R. (Eds.): *Cognition, Education, and Multimedia*, Erlbaum.

13 It must be noted that empirical studies do not uniformly support all of these proposed benefits and there is still uncertainty in the research community regarding exactly what types of learner, content and task characteristics are best suited for hypermedia formats.

14 Jonassen, D., Reeves, T., Hong, H., Harvey, D. and Peters, K. (1997) 'Concept mapping as cognitive learning and assessment tools', *J. of Interactive Learning Research*, Vol. 8, Nos. 3–4, pp.289–308.

15 Ross, T.W. (1993) 'Bloom and hypertext: parallel taxonomies?', *ED-TECH Review*. Autumn/Winter, pp.11–16.

16 Some argue that the user should be able to impose his/her own structure on domain knowledge, in accordance with the constructivist pedagogical principle that learners construct knowledge in personal and idiosyncratic ways. Though some user linking or re-structuring features may be beneficial, we believe that the structure and internal relationships (links) that a domain expert defines are 'content' and are just as important as the expertise encoded in the text.

17 Cleary, C. and Bareiss, R. (1996) 'Practical methods for automatically generating typed links', *Proc. of the Seventh ACM Conference on Hypertext*, Washington, DC, 16–20 March.

18 Luckin, R., Plowman, L., Laurillard, D., Straforld, M. and Taylor, J. (1998) 'Scaffolding learners' constructions of narrative', *Proceedings of Int. Conf. of the Learning Sciences*, pp.181–187.

19 Wertsch, J. (1984) 'The zone of proximal development: some conceptual issues', in Rogoff, B. and Wertsch, J. (Eds.): *Children's Learning in the 'Zone of Proximal Development'*, Jossey-Bass Inc., San Francisco, pp.7–18.

20 Murray, T. and Arroyo, I. (2002) 'Toward measuring and maintaining the zone of proximal development in adaptive instructional systems', in Gouarderes, C. and Paraguacu (Eds.): *Intelligent Tutoring Systems: 6th International Conference, ITS 200*, Springer Verlag, Berlin, pp.749–758.

21 Plowman, L., Luckin, R., Laurillard, D., Stratfold, M. and Taylor, J. (1999) 'Designing multimedia for learning: narrative guidance and narrative construction', *Proceedings of CHI 99*, 15–20 May, Pittsburgh, PA USA: ACM, pp.310–317.

22 Weller, M.J. (2000) 'The use of narrative to provide a cohesive structure for a web based computing course', *Journal of Interactive Media in Education*, Available from: www-jime.open.ac.uk.

23 McAleese, R. (1989) 'Navigation and browsing in hypertext', in McAleese, R. (Ed.): *Hypertext: Theory Into Action*, Ablex Publ, Norwood NJ, Chap. 2.

24 Heller, R. (1990) 'The role of hypermedia in education: a look at the research issues', *J. Research on Computing in Education*, Vol. 22, pp.431–441.

25 Wallace, R.M., Kuperman, J., Krajcik, J. and Soloway, E. (2000) 'Science on the web: students online in a sixth grade classroom', *Journal of the Learning Sciences*, Vol. 9 No. 1, pp.75–104.

26 It should be noted that MetaLinks does not explicitly or directly support the full set of skills addressed in educational software that supports 'scientific inquiry skills' (including hypothesis formation, planning and data analysis skills) but supports a more informal notion of inquiry, i.e. that instructional experiences need to be motivated by and must support learner questions and curiosity.

27 Collins, A. and Ferguson, W. (1993) 'Epistemic forms and epistemic games: structures and strategies to guide inquiry', *Educational Psychologist*, Vol. 28, No. 1, pp.25–42.

28 Woods, W.A. (1975) 'What's in a link: foundations for semantic networks', in Borrow, D.G. and Collins, A.M. (Eds.): *Representation and Understanding: Studies in Cognitive Science*, Academic Press, New York, pp.35–82.

29 Ausubel, D.P. (1963) *The Psychology of Meaningful Verbal Learning*, Grune and Stratton, New York.

30 De Bra, P. and Calvi, L. (1998) 'AHA: a generic adaptive hypermedia system', *Proceedings of the 2nd Workshop on Adaptive Hypertext and Hypermedia, Hypertext '98*, Pittsburgh, June, Available from: http://www.contrib.andrew.cmu.edu/~plb/HT98_workshop/

31 Specht, M. and Oppermannn, R. (1998) 'ACE – adaptive courseware environment', *New Review of Hypermedia and Multimedia,* Vol. 4, pp.141–162.

32 Murray, T., Gartner-Piemonte, J. and Kelleher, P. (2001) 'Evaluating features for conceptual and narrative flow in an adaptive hyperbook', *Proceedings of the International Conference on Artificial Intelligence and Education: AIED-2001*, pp.21–32.

33 Murray, T., Piemonte, J., Khan, S., Shen, T. and Condit, C. (2000) 'Evaluating the need for intelligence in an adaptive hypermedia system', in Frasson and Gautheir (Eds.): *Proceedings of Intelligent Tutoring Systems 2000*, Springer-Verlag, New York, pp.373–382.

34 Results from study 2 indicated that the fact that it required an extra mouse click (the pop-out tab) to use the feature contributed to this, but does not fully account for the low use.

35 Thompson, G.R. and Turk, J.T. (1997) *Modern Physical Geology*, 2nd ed., Saunders Publishing Co, Philadelphia.