Multimedia Learning with Hypermedia

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Abstract

Hypermedia proponents suggest that its ability to make information available in a multitude of formats, provide individual control, engage the learner, and cater to various learning styles and needs makes it the harbinger of a new learning revolution. However, despite nearly two decades of research on hypermedia in education, researchers have not yet solved some of the basic issues raised by this technology. In this chapter, we review empirical studies performed since Dillon and Gabbard's (1998) landmark review in an attempt to analyze and draw conclusions from this diverse and extensive literature.

Introduction

Since Vannevar Bush's ground-breaking article *As We May Think* (Bush, 1945), the idea of using technology to link the world's information resources in new ways has been heralded by some as a revolutionary opportunity to design new instructional media. The term *hypermedia* is commonly used to refer to this type of information resources and is based on the term *hypertext*, coined by Ted Nelson around 1965 to refer to "non-sequential" or "non-linear" text where authors and readers were free to explore and to link information in ways that made personal sense for them (Nelson, 1965). In general usage, the terms are often used interchangeably but to be strictly accurate, *hypermedia* consists of more than linked texts; it includes other forms of media as well, such as images, video, and sound.

Because of the diverse forms of media that can constitute a hypermedia document, hypermedia learning tools became *multimedia* in nature. By multimedia we mean that learning material is presented in both words and pictures, and may also include sound. Regardless of the term, this technology is based on nodes or chunks of information that are linked together and which a user or learner can explore by following links they deem relevant. Abstract as this sounds, the most obvious example of such an information space is the World-Wide Web, wherein the linked structure provides a practically never-ending opportunity for a user to explore multiple documents and to follow paths of exploration as they fancy.

As with many new forms of media, hypermedia was initially touted as the harbinger of a new learning revolution (Fabos, 2001). As discussed in Dillon and Gabbard (1998), proponents tout its ability to provide nonlinear access to information, explore information on demand, provide self-paced instruction, and engage the learner. Hypermedia also caters to various learning styles and individual learning needs by providing information in a multitude of media formats. Debates still exist as to the pedagogical value of many hypermedia applications and, despite multiple experiments, researchers have failed to resolve many of the basic issues concerning the use of this technology for instruction. In the present chapter we review the most recent empirical work in the area in order to help readers make sense of this complicated and ever-expanding literature.

Theories of hypermedia learning

Its advocates see hypermedia as a natural form of information representation that supports the native tendencies of learners to explore and relate concepts. However, as noted by Dillon and Gabbard (1998), there has been limited theoretical analysis underlying much of the work on hypermedia learning, and the situation has not changed noticeably since then. Early discussions of this technology (the period up to 1995, approximately) tended to adopt a naïve associationist view of cognition and emphasized the similarities between linked information nodes and the presumed architecture of human cognition. While a more critical view of hypermedia and cognition has since evolved, formal theories of hypermedia learning have not developed in any substantial way. Instead, existing theoretical models from education and psychology have been applied to certain aspects of hypermedia design and use. The general tension between constructivist and information processing views of learning is mirrored in the hypermedia literature, with behaviorist theories finding little application in this domain.

Hypermedia learning studies frequently make intuitive appeals to certain cognitive theories, such as dual coding (Pavio, 1986) or cognitive flexibility theory (Spiro, Feltovich, Jacobson, & Coulson, 1991). By virtue of the media mix (implying an exploitation of dual coding for cognition) and the ability to restructure information in real time (enhancing flexibility), any number of studies have adopted a weak theoretical stance without formally testing or extending the broader implications of either perspective.

Currently, there is only one dedicated theory of multimedia learning which explicitly aims at guiding our analysis and understanding of learning in hypermedia environments: Mayer and colleagues' *generative theory of multimedia learning*(Mayer, 2001). Building on cognitive psychological theories, Mayer and colleagues assume that learners are limited-capacity dual encoders who actively process information in order to integrate it meaningfully with their existing knowledge (Mayer, 2001). By examining the impact of various hypermedia features on the learner's cognitive processes, the theory points to specific advantages that may be yielded by combinations of modalities (e.g., images with sound) designed to support the integration by the user without overloading limited cognitive resources. The value of this approach can be seen in recent work (Moreno & Mayer, 2000a; Plass, Chun, Mayer, & Leutner, 1998) which has led to the derivation of specific instructional principles for hypermedia learning, e.g., the modality principle, which states that students learn better when visual or verbal information is presented in a congruent format (e.g., verbal information as sound rather than text). This work holds promise for solid theoretical advances in our understanding of multimedia design along the lines of classic cognitive engineering approaches to human-computer interaction.

Alternative theoretical approaches from constructivism tend to deal at a higher level of abstraction, concerned more with the context of learning, task relevance, and ability of, or opportunity for, learners to apply the material to be learned. The work of Spiro and colleagues (Spiro et al., 1991) examines how people can reconstruct information into meaningfully organized wholes to suit a task. Under this theory, less focus is given to determining appropriate modalities and forms of information within a hypermedia and more emphasis is placed on how the tool can facilitate multiple representations for a learner to explore. Indeed, it is an assumption of the cognitive flexibility theory that hypermedia is uniquely suited to learning complex or ill-structured material.

While theoretical developments have been limited, the empirical study of hypermedia has continued to grow and there is no shortage of papers that report how a given group of users perform with a specific design. The present chapter extends earlier reviews and attempts to bring up to the present date a summary of what has been observed.

Reviewing the Reviews

Over the last 15 years several attempts at reviewing the growing literature on hypermedia and learning have been made. Nielsen's (1989) review of 30 hypertext studies compared the effects of various user aspects of hypertext interaction and pointed to the large individual differences that exist in user response to the technology, a finding that has remained remarkably consistent to the present.

Chen and Rada's (1996) meta-analysis of 23 studies on the use of hypertext for a range of information tasks also concluded that the benefits for this technology were mixed. While pointing to the real advantages for hypermedia lying in what they termed 'closed' tasks, those where the user is seeking specific information, these authors also noted that spatial ability was an important factor in determining user response to hypermedia documents.

All reviewers agree that firm conclusions are difficult to draw from available literature. However, several authors have also been highly critical of the quality of research in this area. Landauer (1995) noted that in his review that he could identify only nine studies that were scientifically acceptable. Three years later, Dillon and Gabbard (1998) produced an extensive review of the quantitative, empirical findings on learning outcome from hypermedia. They also noted poor experimental design and flawed analysis in many studies, but drew three basic conclusions that serve as a useful starting point here:

- Hypermedia is generally advantageous for tasks that require rapid searching through large or multiple documents
- Increased control over access to information is not equally beneficial to all users and may even be detrimental for low-ability learners.
- Particular interface designs are best suited to certain learner styles

Since then the literature on this topic has grown but the results continue to be mixed. Liao (1998), Parlangeli et al (1999), and others have compared hypermedia with other forms of instruction and failed to show real benefit for any instructional form. However, the multiple variables that shape learning outcome are being teased out, albeit slowly, and researchers are beginning to pay more attention (although still insufficient amounts) to longitudinal examinations at learning outcome as a result of multimedia use. For example, Yildirim et al (2001) tested 39 ninth grade biology students receiving either traditional instruction or hypermedia on three different outcome measures: declarative, conditional, and procedural knowledge. Although the first post-test showed that there were no significant differences for the three types of knowledge, as is typical of many studies, on a retention test given one month after initial treatment, there was a significant difference in favor of the hypermedia group on all three types of knowledge. These results were found not to be dependent on prior knowledge. Such work requires us to view with caution strong claims based on single trial experiments or tests.

While most of the early reviews compared hypermedia with some other form of instruction, more recent work has compared varieties of hypermedia in order to determine which aspects of the technology have greatest influence on use. In part this may mark a more refined approach to the problem, a reflection of growing maturity in the research effort, but it also may reflect the generally ubiquitous status of hypermedia applications in learning situations nowadays. In the following sections we summarize what these last few years of research have taught us about hypermedia-based instruction. As in Dillon and Gabbard (1998), we emphasize only studies that meet minimal levels of control, and that have assessed learning outcome in some measurable fashion. It is perhaps, by now, not surprising that such literature does not form the majority of writings on this topic. We have divided the literature into three themes:

- Design, which covers the various forms of structure and interface features used to implement the hypermedia;
- Cognition, which covers the all-important psychological and individual differences research into learner response; and
- Context, which covers work examining the learning situation and its impact on hypermedia use.

Design issues

The essence of hypermedia is linked nodes of data, which may include text, video, audio, or graphics. Understandably, the freedom to create new information forms of this kind has resulted in multiple versions of hypermedia instructional materials and consequently, a major research initiative has evolved which attempts to identify the various forms and features that work best for users. While much literature exists on interface design for hypermedia (e.g., (Dillon, 2004), this section is concerned only with design manipulations where learning outcome was studied.

Information structure

In this discussion, the term *structure* is used to describe how the information in a hypermedia is organized – in other words, how the *nodes* are physically connected together via *links*. The simplest structure is *linear* in format, meaning that the user must progress sequentially from one chunk of information to the next, rather like a book, where one page precedes another. *Hierarchical* structures have a ‘top’ node from which all information stems in increasing levels of detail. Information can be linked in a *strictly hierarchical* format, where each node is only connected to nodes on the levels directly above and below it in the hierarchy. Alternatively, each node can also be linked to other nodes at the same level, or links can even skip levels. There is no agreement on what this type of hierarchical cross-referential linking structure should be called. For example, McDonald and Stevenson (1998), and Calisir and Gurel (2003) call this a *mixed* structure but it has also been called *referential* (Lin, 2003) or *hierarchical with partial linearity* (Nimwegen, 1999).

Regardless of terminology, typical studies of structural issues compare various topologies, and measure navigation patterns and learning outcome success. For example, Melara’s (1996) study using a hypermedia tool on the Shortest Path Algorithm (an algorithm for calculating the shortest path between two vertices on a connected graph) on 40 undergraduates found that although structure (hierarchical versus network) did not affect post-test scores, learners spent significantly more time using the hierarchical structure than the network structure, indicating that structure certainly impacts process of use. Shapiro (1998) compared linear, strictly hierarchical, and hierarchical with no navigational cues (which she termed ‘unstructured’) on 72 undergraduate students using a historical hypermedia document, ‘The Gilded Age of America.’ When comparing the learning outcome between the linear and strictly hierarchical structures, those using strictly hierarchical hypertext showed significantly more factual knowledge acquisition based on the number of concept map nodes drawn, but no significant differences were found on link familiarity, short-answer questions, or the essay. No process measures were studied. Shapiro is reticent of reading too much into the concept map measure, but on the whole, these results support the general impression that structure is not a leading cause of learning outcome.

Many other studies support these findings. Spruijt and Jansen (1999), De Vries and de Jong (1997) and McDonald and Stevenson (1996) all reported that while structure affected process measures such as number of navigation problems, experience of disorientation or time spent performing the task, in none of these studies was a significant learning outcome difference reported. Nimwegen et al (1999) asked 80 subjects of different ages and from different departments from the University of Utrecht to answer 24 questions using a hypermedia guide to the city of Utrecht. The structure employed was either a strictly hierarchical or a mixed hierarchical structure. They concluded that users with the strictly hierarchical hypermedia were significantly faster, made significantly fewer deviations or views of superfluous pages, and had a significantly more positive opinion about their insight into the underlying structure of the hypermedia. Schoon and Cafolla (2002) compared the effects of using linear, star, hierarchical, and random structures on 261 undergraduates. Users had significantly better 'Navigational Action Efficiency' scores (a process measurement developed by the authors) when using a star or hierarchical structure than a linear or random structure, but there was no significant difference between the scores of star and hierarchical structure users. Learning outcome was not studied.

The literature is not completely consistent however. Paolucci (1998) compared conventional, branching, and strictly hierarchical structures on 115 fifth-grade students' use of a hypermedia lesson on ecology. Paolucci measured levels of linkage, with conventional being the most interlinked and hierarchical being the least interlinked, and equated this with levels of freedom for the users. The data show that the number of links and the linkage pattern affects outcome as measured by post-test scores, with users of the branching pattern performing the best, followed by hierarchical and conventional. Logical reasoning, as determined by assessing structural knowledge via questions on analogies, associations, relationship proximity judgments, and semantic relationships, was also affected, with the branching group again performing significantly better than the conventional group, but not the hierarchical group. However, because the branching and conventional structures Paolucci used are unique to this study it is difficult to compare these findings to others. In general, it seems that structure will affect learning by influencing how well or how fast a learner can move through a hypermedia document, and despite the possibilities afforded by the technology to structure information in unique ways, hierarchies have real value for many users.

Advance Organizers

The provision of advance organizers can be seen as means of rendering structure explicit to users. While such devices tend to be standardized in print media (e.g., contents pages, chapter headings, abstracts, etc.) the endless possibilities for design within hypermedia means that such representations could take multiple forms thereby complicating any recommendation on their use. While an overview is likely to be beneficial for navigation purposes if it contains direct links to information, its layout and form provide a structure that may not always be optimal for learning purposes or for certain users. McDonald and Stevenson (1999) performed two experiments on low prior knowledge learners to explore the differences between the use of spatial maps (which show the underlying informational structure), text-based content lists, conceptual maps (which show information grouped by concept), and no aid when using a hypertext on "The Nature of Human Learning". In the first experiment, spatial map users were able to navigate more efficiently (in terms of the time taken to locate a node and the number of additional nodes opened) than contents list users, but there was no significant difference in learning outcome although the no-aid group performed worst on both navigation and learning measures. In the second experiment, the spatial map appeared to help navigation the most whereas the conceptual map improved learning the most. Subjects with no aid navigated poorly, but, somewhat surprisingly, learned more than those in the spatial map group, suggesting that having to form linkages and structures for oneself may encourage active processing of the text, which could enhance learning.

This active processing effect was observed in Brinkerhoff et al (2001). They studied the effects of overview mode on attitude, post-test scores, and instructional time. Participants (n=79) either had no overview, a structured overview, or an unstructured overview. Although post-test scores were not affected by mode, having an overview of either type seemed to encourage learners to spend more time on instruction and resulted in a more positive attitude. Yeh and Lehman (2001) also report a beneficial effect for advance organizers. They tested 150 Taiwanese EFL university students to see whether the presence or absence of an advance organizer (in the form of a short overview) affected post-test scores when studying a hypermedia about the creation of the state of Israel. Their results indicate that having an advance organizer did improve post-test performance. These experiments suggest a trend that learners perform better on several levels with advance organizers (regardless of type) than without.

Shapiro performed two experiments (1999; 2000) that considered the use of interactive overviews and learning goals in a hypermedia on fictitious animals by students with a low prior knowledge of biology. The overviews were organized by animal family or by ecosystem. Learners were then given a learning goal that either matched or mismatched the overview. The 1999 experiment (n=46) showed no significant effect of overview type on acquiring explicit knowledge, but those who had an ecosystem overview performed significantly better on the ecosystem posttest. However, having an animal family overview did not seem to affect posttest scores on the animal family posttest. Shapiro speculates that this discrepancy may be due to the pretest selection procedure, which may have favored individuals who had prior knowledge about animal families. The 2000 (n=44) experiment found no effect of overview condition on the total number of responses on a cued-association task, where students were asked to write three topics that came to mind when the name of an animal discussed in the hypermedia was presented. However, overview condition did significantly affect the type of associations students made. Students with the animal family overview made significantly more animal family associations, and those with the ecosystem overview made significantly more ecosystem associations. On a sorting posttest, where students sorted cards into animal families or ecosystems, significantly more students in the animal family group sorted by animal family, whereas in the ecosystem group only slightly more students sorted by ecosystem than by animal family. However, this was a marked change from the pretest sorting strategy, where the majority of students sorted by animal family. Thus, Shapiro concluded that overview type can affect strategy, regardless of initial biases, though how far these results extend beyond sorting tasks is an open question.

Other studies compared different types of advanced organizers without the benefit of a control group, but manipulating a user variable such as cognitive style or knowledge-level to assess possible interactions. For example, Chou and Lin (1998)studied 121 university students to see if map type and cognitive style (according to Witkin's Group Embedded Figures Test, or GEFT) affected searching, cognitive map development, or attitude. The results suggested that global maps, which showed the entire hierarchical knowledge structure, were more helpful than local maps, which showed smaller chunks of the hierarchical structure according to main headings. However, the authors hypothesize that global maps might be too unwieldy for efficient use on a larger-scale learning tool. No interaction on any measure was found between cognitive style and map type. Similarly, Hofman and van Oostendorp (1999) tested 40 first-year university students to see whether structural overviews or lists were more useful in a relatively short hypermedia on ultraviolet radiation. Structural overviews appeared to hinder less knowledgeable users, which the authors speculate may result from drawing the learner's attention to the macrostructure of the text at the expense of attention to the microstructure.

Deriving an overview style is left to the imagination of the experimenter in most cases. Hsu and Schwen (2003) examined 54 university students use of one of three types of "metaphorical" designs, i.e., hypermedia structures built around different forms of organization: a book metaphor, a combination book and folder metaphor, or no metaphor. The participants searched for answers to questions in a lengthy hypermedia on 19th

century American history. Metaphorical cues helped learners find a significantly greater number of correct answers. However, overview metaphor had no significant effect on time spent on task, navigation patterns, or satisfaction. We should note of course, that unless the experiment explicitly forces it, provision of an overview is no guarantee of its use. Niederhauser et al (2000) showed that students tended to examine the topic map either at the beginning or end of a session rather than during use. Given such usage patterns, any topic map may serve as either an overview or a summary.

Mixed media

Perhaps the greatest promise of hypermedia learning tools is the ability to include multiple media, including text, pictures, sound, and video in a unified, easily accessible learning space. Interestingly, many of the studies reviewed made use of hyper*text* only, often citing the limited knowledge about how other media affect the learning process as a reason for using text. Only a few researchers have looked at the effects of media other than text, despite the importance of understanding how such media may benefit learning. Mixed media brings with it many new potential problems, such as appropriate combinations (e.g., is sound a complement to animation or should text and sound be avoided in certain contexts?). This would appear to be a topical area for new research.

Empirical data on the effects of sound in multimedia learning is limited. Kalyuga et al (1999) tested 34 trade apprentices to find ways of circumventing possible split-attention effects. They found that when working with diagrammatic material to determining the proper type of solder for a specific task, the apprentices performed significantly better on post-tests and reviewed the information fewer times when the information accompanying the diagram was read aloud instead of being presented in a textual format (i.e. a caption) on the screen. However, duplicating information by presenting it both visually and aurally – that is, having on-screen text *and* having the same text read aloud - was detrimental to learning.

It seems plausible that sound could be particularly useful if used appropriately, since it potentially adds more information to the learning context, which may complement visual stimuli. Mayer and Moreno (1998) showed that when working with an animation of natural or mechanical processes, providing university students with concurrent narration (that is, coupling the spoken works to appropriate points in the animation sequence) was more beneficial than providing students with concurrent explanatory text. Presumably the text adds to the visual processing load whereas the sound exploits the dual processing capability of learner (see e.g., Wickens, 1992 for an information design model based on resource processing). Two further experiments by Moreno and Mayer (2000a) used the same two animations with concurrent auditory narration, but added irrelevant music, environmental sounds, or both to determine how irrelevant auditory material affected performance. In both experiments, groups receiving additional auditory material performed worse than the group that did not, demonstrating that irrelevant auditory material was detrimental to learning, serving as a distracter rather than an enhancer.

The use of graphics and video or animation in conjunction with text would seem to be an important area of study for multimedia though there are few formal experiments in the literature yet. Kalyuga et al (1998) tested three instructional formats (integrated diagram and text, separate diagram and text, and diagram only) on trade apprentices with different levels of prior knowledge to determine how different types of instruction affect learning. In a series of three experiments on electric circuits, they found that low knowledge level apprentices preferred diagrams with text, while more knowledgeable apprentices found integrated textual explanations redundant and thus preferred diagram-only instruction.

In two similar experiments, Kalyuga et al (2000) tested trade apprentices on their understanding of how to determine R.P.M.s needed for a cutting speed nomogram. Apprentices used a diagram with visual text, a diagram with auditory text, a diagram with both auditory and visual text, or a diagram only. Although the apprentices initially performed best on the posttest using the diagram with auditory text, after two training sessions, the diagram-only format performed just as well. In the second experiment, the diagram only and diagram with auditory text formats were compared. The authors found that more experienced learners performed better on the posttest with the diagram-only format. These results suggest that learner experience and competence are important since preferences for one type of material over another may shift as experience is gained and competency improves. However, the success of diagram-only as witnessed by Kalyuga et al is probably highly context-dependent.

Learner control mechanisms

Proponents of hypermedia learning have argued that one of its greatest benefits is that the learner can control the learning situation and this factor was deemed generally significant in Dillon and Gabbard's (1998) review, although there is no consensus on what constitutes control in such learning situations. Jacobson et al (1996) provided different levels of learner control to 69 university student by either having the computer provide case-specific information or allowing the learner to select information as deemed necessary. The results suggest that providing learners with flexible control leads to improved learning on short answer and certain types of essays. Yeh and Lehman's (2001) study of students learning English as a Foreign Language (EFL) manipulated control by allowing either students or the computer to set the pace of material presented. Students who controlled the pace and sequence of the hypermedia had significantly improved recall scores, although it is worth noting that this form of learner control had no effect on satisfaction.

Elements of learner control are also associated with generative activities, requirements or opportunities for learners to take notes, summarize or otherwise perform an activity while learning. Astleitner (1997) experimented with the benefits of using a memo pad, with mixed results. Thirty-eight high school students used a hypermedia on solar energy, and half were encouraged to use memo pads during interaction, but were not allowed to refer to their notes during the post-test. He found that action-oriented learners (as determined by the action control subscale (Kuhl, 1985) acquired significantly more intentional (goal-based) knowledge when they were *not* using a memo pad, whereas non-action-oriented learners acquired significantly more intentional knowledge when they *did* use a memo pad. On the other hand, using a memo pad led to significantly more incidental (non-goal-based) knowledge acquisition, regardless of whether or not the learner was action-oriented. Barab et al (1999)reported no effect for such generative activities however.

Conclusions

Issues of interface design for hypermedia learning contexts will likely remain at the forefront of research for some time. While the various structural forms that can be exploited have not been fully explored, it is clear that structure impacts the process of use in a significant manner, with hierarchical structures having some advantages in many instances. It remains to be seen if innovative structural forms may evolve to yield greater benefits. Mixing media remains an area of enquiry that sorely needs greater empirical study. As technology enables radically new designs of instructional materials, the possibilities offered by hypermedia are tremendously exciting, but exploiting these possibilities requires significant work to determine how the combination of media, in particular, can work to the advantage of humans in learning situations.

Individual Differences in Cognition

Studies of hypermedia designs represent a more recent trend in the literature as researchers seek to uncover the impact of particular aspects of hypermedia interfaces on information gain and learning. There still remains, however, broad interest in the effects of hypermedia on types of learner, an effect that has been shown to influence performance repeatedly. In the present section we report on the latest work in individual differences where researchers seek to understand what characteristics of the learner influence how learning occurs with this technology.

Domain and prior knowledge

There is mounting evidence that users' prior domain knowledge has a significant impact on their pattern of interaction with hypermedia in learning situations. Low prior knowledge subjects either seem to experience more difficulty (Lawless & Kulikowich, 1996; McDonald & Stevenson, 1998) or have lower posttest scores (Kraus, Reed, & Fitzgerald, 2001; Niederhauser et al., 2000; Potelle & Rouet, 2003) than high prior knowledge users when interacting with hypermedia learning tools. It has been suggested that those who are less familiar with the subject matter cannot easily create new content representations, a problem that is exacerbated by the node-and-link structure of hypermedia. There is an unfortunate irony to this since hypermedia has long been advocated as a way of 'leveling the playing field' and allowing all learners to proceed in a manner that suits their unique learning process.

As discussed in the Design section, while it is no simple matter to determine the effects of structure across multimedia learning activities, it would appear that certain structural variables interact with specific learner types. Calisir and Gurel (2003) reported an interaction between structure and reading comprehension scores (the outcome measurement) for non-knowledgeable students, indicating that a hierarchical topology may be more beneficial for such learners. A similar manipulation by Potelle and Rouet (2003) tested 47 university students with either high or low prior knowledge in Social Psychology to see if concept map type (which were based on linear, strictly hierarchical, and mixed hierarchical structures) affected learning. Their results suggested that, for low prior knowledge users, a hierarchical map and underlying hierarchical structure improves learning outcomes at the macrostructural (e.g. categorical relationship), but not the microstructural (e.g. factual) level.

McDonald and Stevenson (1998) examined students (N=30) with different levels of knowledge interacting with strictly hierarchical, mixed hierarchical, and network (i.e. nonlinear) hypermedia structures. They found that, regardless of knowledge level, structure directly influenced processes such as browsing and navigation, in terms of the number of nodes opened, number of nodes repeatedly opened, time taken to answer questions, and number of additional nodes opened. A mixed hierarchical structure produced the best performance, followed by a strictly hierarchical topology and finally a network topology. In general, knowledgeable participants performed better than non-knowledgeable participants. McDonald and Stevenson suggest that prior conceptual understanding of the information may reduce disorientation problems for the knowledgeable users.

However, both of Howard-Jones and Martin's (2002) studies on pre-service teachers using a hypermedia on cutting and joining materials indicate that teachers who scored lower on the pretest scored higher on the posttest. In other words, the low prior knowledge teachers learned more from the treatments. A study by Yildirim et al (2001) also found that prior knowledge does not affect learning outcome. They considered prior knowledge as a factor when comparing the short and long term effectiveness of traditional and hypermedia instructional techniques on 39 9th grade biology students. No significant difference was found between the two groups on a short-term posttest, and all of the mean differences in test scores were attributable to prior knowledge. However, the group that received hypermedia instruction performed significantly better on a long-term retention test administered one month after the initial experiment, although prior knowledge was not found to be a factor in these differences. No explanation was offered for the lack of influence of prior knowledge, however these data suggest that certain hypermedia features may significantly affect the rate of learning, and this is an area that clearly warrants more detailed examination.

Spatial Ability

Since many users describe feeling lost or disoriented in hyperspace, helping people navigate has been one of the primary concerns of hypermedia developers over the years. Spatial metaphors (such as a house, desktop, or street) are sometimes used to mitigate this problem, on the theory that users will relate to familiar situations in the physical world (for a thorough discussion on the spatiality of hyperspace, see Boechler (2001)). A study by Padovani and Landsdale (2003) supports this argument. They tested 230 university students using two different hypermedia systems, one of which was based on a spatial metaphor and the other of which was based on a non-spatial metaphor. The spatial metaphor produced higher performance (in terms of task completion times) under all conditions. Thus, it is clear that the spatiality of the virtual world is an important aspect of designing usable hypermedia learning tools; consequently it follows that a user's spatial skills may also be important in dealing with hyperspace.

Spatial skills are typically determined using a standardized test, for example in Nilsson and Mayer (2002), where they used the Paper Folding test and Baddeley's three-minute intelligence test. Although the primary goal of their experiment was to test the cognitive load theory, spatial skills were also considered. Learners who had high scores on the paper-folding test were able to navigate more efficiently than those with lower scores, and learners who did well on the three-minute intelligence test were also marginally more efficient at navigating ($p < .07$). Nilsson and Mayer concluded that these two individual differences determined navigation efficiency for the experiment, although learning outcome was not studied.

The effect of skills such as spatial ability can be complicated to untangle. The study by Plass et al (2003) mentioned earlier used the Card Rotation Test from the *Kit of Factor-Referenced Cognitive Tests* (Ekstrom, French, & Harman, 1976) to assess the spatial ability of 152 English-speaking university students taking a second-year German course. Their study examined whether the use of either visual (i.e. pictures) or verbal (i.e. textual) annotations helped users with different levels of spatial skills and verbal skills when reading a hypermedia story in German. When students had visual annotations for vocabulary words, the high verbal and high spatial ability students outperformed low ability students on recall of word translations. However, there was no difference between the two groups when the students had verbal annotations. Visual annotations produced the worst text comprehension for all learners. As hypothesized, the results were correctly predicted by Mayer's (2001) generative theory of multimedia, which states that visual information requires spatial processing skills, thereby giving high spatial ability students an advantage in a visual environment.

Cognitive style / learning style

The longstanding interest in cognitive style among educators is based on the view that processing differences among learners need to be accommodated in the design of instructional contexts and technologies. The most common cognitive or learning style tests that have been used in hypermedia evaluations are Kolb's Learning Style Inventory (LSI) (1984) and Witkin's Group Embedded Figures Test (GEFT) (1971). The LSI divides people into varying levels of convergers /divergers or accommodators/assimilators. Convergers tend to bring together pieces of knowledge into a single topic to deduce an answer, whereas divergers rely on brainstorming and idea generation to solve problems. Assimilators supposedly solve problems by inductive reasoning, while accommodators plan and experiment (Kolb, 1984). Individual learning styles are a mix of these four modes, although the converger/diverger accommodator/assimilator scales are continuous, so an individual can be more or less strongly inclined toward one mode or another. The GEFT requires subjects to identify a simple figure within a more complex pattern. People who are good at finding the simple figures are said to be more *field independent*, which is defined by Witkin et al (1977) as "the extent to which a person perceives part of a field as discrete from the surrounding field as a whole, rather than embedded in the field." Those who find it difficult to extract the pattern from the field are classified as *field dependent*, and are generally considered to be more sensitive to contextual effects.

Since Dillon and Gabbard (1998) reported that individual differences in information processing were an important part of the puzzle in explaining hypermedia's effects on learning, there has been a steady stream of further work exploring cognitive style. Rasmussen and Davidson-Shivers (1998), for example, used the LSI to test learning style and studied learner control based on hypermedia structure to determine the effect on both immediate and delayed test performance. Active (accommodative) learners, who tend to experiment during the learning process, scored best when using the hierarchical structure in both the immediate and delayed post-tests. These findings are somewhat contrary to previous studies which suggested that active learners perform best when high levels of learner control are available, and the authors speculate that for this study, active learners may have preferred the efficiency of the strictly hierarchical structure. On the other hand, reflexive (assimilative) learners performed best when using a strictly hierarchy structure that also included the ability to link together (i.e. associate) individual nodes. The authors suggest that the hierarchical structure provided these learners with the necessary structure to suit their learning style, but also with the opportunity to add their own interpretations of the information via the linking capability.

Kettanurak et al (2001) studied 154 undergraduate students to determine the effects of the LSI and three interaction modes on learning: no interactivity (a linear hypermedia); low interactivity, (a linear hypermedia that enabled learners to control information presentation order, pacing, and provided the ability to review information); and high interactivity, (where, in addition to the features in the low interaction mode, the program kept track of the learner's location, provided feedback from questions at the end of each section, and had an index feature). Modes of interaction were found to have a significant effect on attitude, regardless of learning style, with students preferring high levels of interaction, though it should be noted that the no interaction condition was preferred to low interaction as employed here.

Two studies reviewed used the GEFT to determine cognitive style. Chou and Lin (1998) studied 121 Taiwanese university students using a hypermedia "Introduction to Computer Networks" to see if cognitive style affected searching, cognitive map development, or attitude. Results showed no main effect for cognitive style on the number of search steps learners used, their search efficiency, the ability to complete a search task, or attitude toward the experience. However, when judging the number of nodes in the hypermedia (estimation accuracy), cognitive style approached significance ($p<.052$). Here, field-independent students scored significantly better on the cognitive map test, which tested students' ability to reconstruct the relationships among nodes in the hypermedia.

Cognitive style seems to mediate hypermedia-based learner performance in a complicated manner. For example, Palmquist and Kim (2000) tested 48 university students performing information searches of a university web site. They reported a significant effect for field dependency but found its importance tended to be minimized as users gained experience. Field independent and field dependent students with high on-line experience spent almost the same amount of time on task, but field dependent students with little on-line experience tended to spend far more time and visit more nodes than the field independent students with the same amount of on-line experience. This may point to the impact of practice and once again, the need to study users over longer time slices than a single trial.

Plass et al (1998) tested the potential effects of the verbalizer or visualizer learning preference, based on the Visualizer/Verbalizer Questionnaire by Kirby (1988) and the Edmonds Learning Style Identification Exercise (Reinert, 1976). One hundred and three university students used a hypermedia on German literature, and they were allowed to select which type of annotation they wanted to use (none, verbal, visual, or both verbal and visual) when they encountered an unfamiliar German word. The results indicated that visualizers performed better on vocabulary that had visual-only connotations, whereas verbalizers performed better on vocabulary that had verbal-only connotations. These findings demonstrate the importance of matching learning style with instructional material, at least in the case of visualizers and verbalizers. Ford and Chen (2001) came to a similar conclusion, that matching cognitive style to learning experience was important. They had 73 post-graduate students create HTML pages using instructional hypermedia that was either matched or mismatched to their cognitive styles, as determined by Riding's Cognitive Styles Analysis. The overall gain for students in matched conditions was significantly higher than for those in mismatched conditions.

Conclusions

Individual differences remain a major concern in the educational literature on learning and it is clear that for hypermedia, such differences can significantly impact the experience and performance of learners. Given the myriad cognitive style dimensions that have emerged over the last century of research into learning, it is important to identify the most likely candidates for empirical work and to determine how these differences manifest themselves in specific tasks or may be accommodated within specific designs. Domain knowledge is an obvious distinguisher of the type of learning environment required, but it would now appear that spatial ability is a reasonable predictor of user response on certain measures, such as navigation performance. Field dependence/independence is a most popular style dimension and seems to mediate the performance of inexperienced users. Tracing such differences over time remains a research problem in need of far more study.

Context Issues

Hypermedia learning situations can vary tremendously – learners may have different goals, may be working with different sized documents, may be in different learning situations, etc. Instructional content and presentation formats vary widely as well. Since the majority of the studies reviewed in this paper do not make use of real-world hypermedia learning tools being used in an actual educational situation, it is important to consider context factors in experimental hypermedia, especially if we intend to generalize findings to a real-world setting.

Types of study employed in this literature

More than 80% of the studies reviewed in this chapter used university students (including undergraduates and graduates) as experimental subjects. Three studies used high school students, and two used fifth-grade students. Only one study was performed on older adults. While it is clear that university education is an important location for the exploitation of hypermedia technologies, it is certainly not the only place where learning occurs and there is a very real opportunity for new studies to explore other contexts of use.

Typically, in studies of hypermedia, learners are asked to perform a reading-for-comprehension- task, where they were told to take as much time as necessary to use a hypermedia document before being tested. Fully one-quarter of these studies also asked learners to perform a search-and-retrieval task, where learners were given questions for which they were to use the hypermedia to locate answers. We noted eight studies that used only search-and-retrieval as the experimental task.

Descriptive details of the hypermedia documents used in these studies are not always provided. Since it is likely that dealing with a large, multi-page document structured with multiple links and a map will feel different than interacting with a four or five node document, it would help all of us to gain a better sense of the learning context if authors provided such details consistently. Our synthesis of these details indicates that most of the research is conducted on documents consisting of no more than 60 nodes. Only11 studies used hypermedia with more than 60 nodes, and only 6 of those had more than 100 nodes. While ‘node count’ is an ambiguous measure, half the studies where details were provided reveal test documents with less than 2000 words. Apparently we are not yet in the multimedia age, since over half of the studies that reported these details used text-only documents as test materials. Only 8 of the studies used more than three types of media (including text, graphics, audio, video, or animation). Overall, we are seeing research results from a very narrow range of hypermedia instantiations.

Only three studies required the learner to use the hypermedia in an active, applied manner (creating Web sites and designing a children’s playscape). An additional three studies focused on comprehending a foreign language, and four looked at learning mechanical procedures. Factual knowledge gain, measured by a post-task test, was by far the most common evaluation of outcome conducted. Analyzing navigation patterns, tracking time on task, having the learner draw concept maps, and writing short essays were also used regularly.

The subtle effects of contextual issues can be observed in a study by Moreno and Mayer (2000b). They reported the results of five experiments on the use of personalized messages in hypermedia learning. Messages were either written in a personal style, from the 1st or 2nd person perspective, or in a neutral 3rd person point of view. In experiments 1 and 2, students used a hypermedia on lightening formation, and in the experiments 3, 4, and 5, they played a game about environmental science. Experiments 1, 3, and 5 provided spoken (auditory) messages, while experiments 2 and 4 provided on-screen textual messages. Across the five experiments, students who received personalized messages performed significantly better on problem solving transfer tests and retention tests than students who received neutral messages. The authors suggest that these results indicate that students in a multimedia-learning environment should be addressed as participants rather than subjects for optimal learning outcome.

Gender

Gender is typically not the primary focus of studies on hypermedia learning, however several studies considered it as a variable. In fact, only the study by Leong and Hawamdeh (1999) focused specifically on whether or not gender is a factor in hypermedia use. They studied the attitude toward hypermedia instruction of 40 fifth-graders in Singapore (17 boys and 23 girls) but the lack of statistical analysis by the authors led them to conclude only that there may be a difference in attitude between boys and girls.

Reed and Oughton (1997) tested 18 graduate students to determine whether prior computing experience or gender affected navigation style. There was no significant effect between gender and the number of linear or non-linear steps taken, suggesting that, despite popular belief gender, is not a factor in navigation patterns, at least in hypermedia (though see Ford et al (2000) for a contradictory finding on use of indices, where females demonstrated greater use than males). Beccue et al (2001) came to similar conclusions in their study of the effects on audio in hypermedia on 86 university students. They found no significant difference in performance on either the labs or post-test scores between men and women either with or without audio.

While performance may not be directly affected, Ford and Chen (2000) found that women made fewer requests for guidance than did men. Schoon and Cafolla (2002) had somewhat mixed results when they considered whether gender was a factor when using different hypermedia structures. Although it took women fewer steps to find a specific node in the system, women had more restarts (i.e. jumps back to the home page, a common user behavior when lost or disoriented) than did men for the linear, star, and random web sites.

Task and goal effects for hypermedia learning

Several authors have suggested that different forms of hypermedia best meet different learning goals. For example, Curry et al (1999) studied 50 university students using a hypermedia on Lyme disease to see how learning goals affected both general knowledge recall and concept map construction. The experimental group was given a scenario about a person with Lyme disease and asked to determine whether the individual had a clear understanding of the facts about the disease. They authors found that although there was no significant difference between the two groups on the general knowledge recall, students with general learning goals tended to construct hierarchical maps (with the main idea and subordinate concepts listed below), whereas participants with specific learning goals were more likely to construct relational concept maps (with conceptual links between concepts that were not a part of the original hypermedia). This suggests that learners who have a specific goal in mind make their own connections amongst concepts presented in a hypermedia, and the technology may have different benefits or might best be designed differently, when applied in such learning tasks.

Dee-Lucas and Huston Larkin (1999) tested hypertext segmented on different levels (more or less segmentation) combined with goal type (problem-solving or information-finding) on 64 university students to see if different levels of informational segmentation might be appropriate in different task situations. The results suggested that less-segmented hypertext may be more appropriate for goals where learners need to become familiar with a wide range of content, whereas more segmented hypertext may be better for narrowly defined goals such as locating specific or target information. Zumbach and Reimann (2002) studied 60 adults to see how different types of goals affected learning outcome. Participants were divided into three groups based on goals: 1) the *strategy* group, which received pre-treatment training in asking questions before using the hypertext so that users could formulate their own goals; 2) the *goal-based scenario* group, which was given an authentic task to complete while using the hypertext; or 3) the *control* group, which had no specific goal, and received identical information to that provided in the hypertext, but in a tutorial format with question/answer sessions after each module. Zumbach and Reimann concluded that while learners in the *goal-based scenarios* group were significantly more motivated and gained significantly more structural knowledge of the information, learners in the *control* group using the tutorial format actually gained significantly more factual knowledge than either of the other two groups. Such results are a salutary reminder that newer forms of presentation are not always pedagogically better than traditional forms.

Conclusions

The variability we can see across hypermedia studies has tended to be viewed as a source of difficulty for extracting general findings. In fact, while it is true that no two test systems are identical, the real source of variability lies neither in the applications nor the learners studied. The types of hypermedia used also tend to be fairly restricted and most test subjects are college students. There is a typical learning task, at least in this literature, and it most likely involves reading to learn, or at least to be able to pass some form of comprehension or memory test afterward. Since learning goal seems to drive much of learner behavior, this variable really needs more systematic manipulation in future research for us to determine what hypermedia may really offer us.

Future research might also usefully consider extending the tasks and outcome tests used to capture data on a greater range of learning situations. Perhaps more importantly, studies of users with a variety of educational backgrounds and ages would add useful information to the current literature.

Discussion and Conclusions

Despite nearly two decades of research on hypertext and hypermedia learning tools, we are still a long way from knowing how best to exploit the power of this technology to support learning. It is clear that large individual differences exist among learners and that the freedom to jump and move at one's own pace through material is not equally beneficial to all. Despite these and other limitations, research is making progress on explaining the relevant phenomena.

Simple comparisons across media are really not terribly informative. Learning is complex and influenced by multiple factors. Certainly there is no one hypermedia application that can be considered truly representative of the technology in a cross-media comparison, but more importantly, gross media comparisons tend to hide the primary effects of key variables and render most differences non-significant. Over the last decade these lessons seem to have been learned and much of the recent empirical work in this area has sought to compare forms or types of hypermedia to identify the variables that matter. This is progress of a sort.

The ultimate question that we ask here is whether or not hypermedia is a real step forward for learning. The answer is the caveat-laden 'it might be', if the appropriate factors are considered. In the interests of brevity, we provide a highly simplified set of guidelines that seem warranted from the empirical literature reviewed in this chapter:

- Not all learning tasks are equally well supported by hypermedia – determining how learners are to experience and use the material is crucial to designing effective interfaces to information.
- Individual differences, such as domain and prior knowledge, spatial skills, learning styles, etc., should be considered in designing and implementing any hypermedia.

- Providing advance organizers can aid navigation and perception of structure.
- Unless the information to be presented demands otherwise (through convention, genre etc.), hierarchical structures seem to provide a suitable layout for the majority of users.
- Congruency of format for visual and verbal information presentation can assist cognitive processing for most users.

Future research must attempt to broaden the learner population studied so as to include older adults, children, and learners who have not had the advantages of college education. Similarly, there is great potential for task analysis to help determine where linked structures and specific media combinations might have the most applicability. Though it is a problem for all studies of human-computer interaction, there is a real need here for extended evaluations of learners over time since it is clear that single task performance measures are not simply extended to predict long-term learning with interactive media.

The educational literature could learn lessons from the broader design literature of human factors, applied psychology, and information design. While there is no silver-bullet to be found in these literatures, all have concerns with understanding user behavior with interactive systems. As McKnight et al (1991)predicted, hypermedia has become an interface standard, and it is increasingly true that the differences between a learning tool and any other digital information space are difficult to draw firmly. Given this, the literature on user navigation, search performance, reading speed, scanning ability, and so forth can all provide some relevant insight into the actions of learners in hypermedia spaces.

As always, the best step forward will be made when an appropriate theoretical articulation is provided which can explain human performance and cognition in such environments. Perhaps the clearest sign of progress being made in this area is the emergence of Mayer's (2001) generative theory which shows potential to unify the range of cognitive perspectives that have informed much work on user cognition. Its emergence within the educational field is surely a pointer for new work here but it is our view that it could also be of value in related fields such as web design for non-learning activities. Such an argument could not be convincingly made a decade ago, and thus it is one indicator of genuine progress within this field. The next decade may prove the most fruitful yet for educational hypermedia research.

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Glossary

***Advance organizer* –** a means of rendering structure explicitly to users. Common advance organizers include site maps and textual overviews or summaries.

***Generative activity* –** when learners must perform an activity, such as note taking, summarizing, answering questions, etc. while learning.

Generative theory of multimedia learning - learners are limited-capacity dual encoders who actively process information in order to integrate it meaningfully with their existing knowledge. Developed by Mayer and colleagues.

***Group Embedded Figures Test* –** developed by Witkin to determine learning style, it groups people based on their ability to identify simple figures within a more complex pattern. Those who are good at finding the simple figures are said to be more field independent, and are less subject to contextual effects, while those who are more field dependent are more greatly affected by context.

Hypermedia - consists of more than linked texts; it includes other forms of media as well, such as images, video, and sound. Often used interchangeably (though technically incorrectly) with *hypertext*.

Hypertext - coined by Ted Nelson around 1965 to refer to "non-sequential" or "non-linear" text where authors and readers were free to explore and to link information in ways that made personal sense for them.

Learner control mechanism – a technology that enables the learner to control the learning situation.

Learning Style Inventory (LSI) – developed by Kolb to determine learning styles based on varying levels of convergers/divergers or accommodators/assimilators. Convergers tend to bring together pieces of knowledge into a single topic to deduce an answer, whereas divergers rely on brainstorming and idea generation to solve problems. Assimilators supposedly solve problems by inductive reasoning, while accommodators plan and experiment. Individual learning styles are a mix of these four modes, although the converger/diverger accommodator/assimilator scales are continuous, so an individual can be more or less strongly inclined toward one mode or another.

Multimedia - material is presented in both words and pictures, and may also include sound.

Structure- in the context of this chapter, how information, chunked into *nodes*, is connected together via *links*.

Topology – the way in which information *nodes* are connected together via *links*. Can be used interchangeably with *structure*.