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Designing an Effective Hypermedia Learning Tool

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Abstract: The non-linear structure of hypermedia allows authors to better represent the full complexity of domains. However, this non-linear structure also represents a challenging and novel landscape for readers. Despite many claims, the potential of hypermedia as a tool for learning remains largely unrealized. Based upon research in cognitive science, we first propose a small set of principles to guide the design of hypermedia-based learning environments. We then describe how these principles were used to guide the development of a hypermedia system that embodied the domain of CGI, a program of professional development designed to improve the quality of teachers' mathematics instruction. We conclude by reporting the results of an experimental study of the effectiveness of the hypermedia system as a tool for learning.

Introduction

The advent of hypermedia and hypertext affords new forms of literacy. In some accounts, hypermedia and hypertext expand the "writing space" by creating opportunities for multidimensional (hyper) structure [Bolter, 1991]. Yet it is not clear whether or not this expansion of the writing space is accompanied by expansion of the "learning space" for its readers. Despite many claims, the potential of hypermedia as a tool for learning remains largely unrealized. Based upon research in cognitive science, we propose a small set of principles to guide the design of hypermedia-based learning environments. Because general principles about learning with hypermedia can only be tested in the crucible of a particular domain, we go on to sketch the major dimensions of Cognitively Guided Instruction (CGI), a program of professional development designed to help teachers improve the quality of their mathematics teaching. We then describe how the design principles were realized in the context of a learning tool for CGI. We conclude with a brief summary of results of an experiment designed to test the effectiveness of the hypermedia system as a tool for learning.

Design Principles

The non-linear ("web-like") structure of hypermedia is radically different from that of traditional texts. Consequently, hypermedia has the potential to better represent the full complexity of a domain and to provide learners interaction with the domain. However, this non-linear structure also represents a challenging and novel landscape for readers. The representational potential for hypermedia and the challenge that it presents to readers intersect one another during the design process. Although cognitive science is multidisciplinary and still evolving, it can nevertheless serve as an important source of insights about what might be worthy of consideration when designing hypermedia systems for learning. We express this relationship between learning with hypermedia and insights garnered from cognitive science as a set of design principles.

Use non-linearity to "criss-cross" the landscape

Cognitive Flexibility Theory [Spiro, Coulson, Feltovich, & Anderson 1986] characterizes domains as conceptual landscapes. Spiro et. al. maintain that for complex, ill-structured domains, effective learning requires that readers "criss-cross" sites (e.g., concepts in the domain) in this conceptual landscape from several different perspectives or "lenses." Although "criss-crossing" the landscape in traditional texts is difficult at best, the link-node structure of hypermedia seems well-suited to "criss-cross" the conceptual landscape of complex, ill-structured domains.

Make the structure of the domain visible

Novices and experts represent domain knowledge differently. Unlike novices, experts do not represent pieces of knowledge in isolation, but rather, they tend to have rich structures that relate pieces of information together [Chi, Glaser, & Rees 1982]. To help learners transition from novice to expert knowledge representations, hypermedia's link-node structure should encapsulate the associations of the target domain. In other words, the conceptual landscape of the domain should be explicitly modeled by the representational landscape of hypermedia. To make these expert representations explicit, hypermedia links should be *typed*, so that readers can infer the nature of connections. Furthermore, links need to be clearly signaled (e.g., iconic buttons or emphasized text) to cue readers to attend to these connections. Readers also need navigational tools that display more global representations of the domain (e.g., a graphical browser).

Make navigation easy

The non-linear structure of hypermedia information affords new representational forms for authors. However, navigating non-linear structures puts additional working memory demands upon readers [Conklin 1987, Recker 1994]. Because working memory plays a key role in text comprehension [Just & Carpenter 1992], navigation and comprehension are in direct competition for working memory resources. When the processes of navigation and text comprehension jointly exceed working memory capacity, readers can become "lost in hyperspace." To maximize the resources available to text comprehension, navigation should be made as easy as possible for readers. To this end, hypermedia systems can take advantage of readers' familiarity with traditional texts by providing electronic counterparts to tools such as indexes, outlines, and bookmarks. However, there is more to the process of navigation than is afforded by these familiar tools. Readers also need tools that allow them to remember their trails, to backup along paths, and to survey and choose the next "site" to visit in the conceptual landscape. Moreover, navigational tools should be rendered in ways that display these conceptual neighborhoods to readers.

Provide learners opportunities to learn by example

When the concepts to be learned are complex, are "criss-crossed," or difficult to explicitly state, examples are widely used because they implicitly possess the properties that they refer to [Goodman 1976]. Example- or case-based treatments of complex domains have enhanced learning in a variety of complex, ill-structured domains including business, law, and medicine [Williams 1992]. Because hypermedia can provide examples in a variety of media formats (including video), hypermedia systems seem well-suited to deliver example-based learning.

Layer annotations and examples

In most hypermedia systems, when a user clicks on a link, the present screen of information is replaced with a new screen of information. In some instances, this screen replacement strategy can become problematic for learners. For example, when learners view an "example," they are viewing an "example of something" in the domain. To make the connection between the "example" and the "something" (e.g., a principle), readers must have cognitive access to both. In these instances, instead of a screen replacement strategy, examples and annotations should be "layered" on top of the anchoring text (e.g., put in a superimposing window), such that both pieces of information are displayed simultaneously.

Cognitively Guided Instruction

We used the previously mentioned design principles to guide the development of a hypermedia system that encapsulated the domain of Cognitively Guided Instruction (CGI), a professional development program for primary grade mathematics teachers [Carpenter et. al. 1989]. In CGI, teachers learn about how young children typically think about the semantics of arithmetic word problems and how children's strategies for solving these problems evolve over time. Consequently, the design of the hypermedia system, HyperCGI, focused on the semantics of word problems, and the strategies children invent to solve them.

Design and Development of HyperCGI

We applied the design principles discussed previously to develop a system, HyperCGI, to foster the professional development of elementary school mathematics teachers. The completed system contained 66 screens of information and 165 layered annotations and examples. 96 of the annotations provided access to 32 video episodes of children's problem solving. The remaining 59 annotations were primarily text elaborations. In the sections that follow, we briefly describe how we implemented each of the cognitive design principles described previously.

"Criss-crossing" the landscape

The conceptual landscape of HyperCGI includes information on the semantics of word problems, typical solution strategies, expert commentary, examples of children's problem solving, and developmental learning paths. The conceptual landscape of HyperCGI can be browsed with three main viewpoints or "lenses:" problem types, solution strategies, and examples. From the viewpoint of problem types, the semantics of problem types focuses the information and is associated with text examples and likely solution strategies. In the solution strategy view, the strategies that children invent provide the primary focus with associated information on problem types and relevant examples of children's problem solving episodes. The third view emphasizes a learn by example approach. In this view, readers interact with *galleries* that index a library of problem type and solution strategy examples.

This conceptual landscape is explicitly criss-crossed by links that associate different nodes of information, and is implicitly criss-crossed in the *guided tours* facility. Using tours, readers take a previously defined path through the web-like structure of HyperCGI. The paths defined by the tours have been developed in advance to provide "ideal learning paths" to readers.

Making the structure of the domain visible

HyperCGI uses typed iconic links to clearly signal connections in the domain. The link types were based upon the semantic relationships in the domain (e.g., classes of problem types, examples). HyperCGI does not use graphical browsers to convey structure to readers, primarily because they are nearly impossible to use in large-scale hypermedia [Conklin 1987]. Instead, a dynamic *index* tool is used to display the structure of the domain to readers. Initially, the index displays an alphabetical listing of every screen in the system.

Readers can click on any entry in this index to display a new list of all screens linked to the selection. The icon that represents the link type that connects these screens to the selection is displayed with each entry in the new list. Entries in this new list can also be expanded to show further connections. For hierarchical structure, the *outline* tool is used to convey relationships to readers. Both the index and outline can be used to navigate — readers can double-click on any entry to reach the selected screen.

Navigation

To make navigation as easy as possible, HyperCGI provides a number of navigational facilities that allow for individual differences in learners. The *outline*, *index*, and *bookmarks* tools serve as counterparts to familiar forms available in traditional texts. *Next* and *prior* buttons are always available to readers, to allow them access to some predefined linear ordering of information. Readers can also sequence information using the *guided tours*, allowing them access to predefined sequences. HyperCGI also provides a number of trail management features. For example, *footprinting* indicates to readers what information has already been visited. For example, screens that have been visited display a blue footprint icon in the upper-left hand corner to indicate that the present screen has already been visited. Footprinting information is also integrated into links, outline entries, index entries, and annotation and examples. Readers can also easily retrace their paths through the web-like structure by selecting an entry from the *history* menu, or using the *backtrack* button.

Learning by example

Examples of children's problem solving episodes are embedded on most of HyperCGI's screens. Because it is often hard to relate video examples to the concepts they are meant to exemplify, explanatory text usually accompanies these video examples. In addition to these embedded examples, *galleries* provide indexed libraries of text examples of problem types and video examples of children's invented solution strategies.

Layering

HyperCGI makes extensive use of layering, especially when understanding the new information to be displayed is highly dependent upon access to the current information. Thus, all annotations including expert commentary and video examples are layered in pop-up windows. Navigational tools also appear in their own layered windows, and do not replace information already on the screen. *Short definitions* are also layered and provide users access to brief definitions of key terminology in HyperCGI. Context-sensitive *balloon help* is a form of layering that provides help text for any item in the system.

Experimental Study

We conducted an experiment that contrasted learning with HyperCGI and learning with text. Because media studies are costly to conduct and interpret, we employed a novel single-subject research methodology that afforded sound inference. This study used a modified form of the single-subject multiple-baseline design [see Kazdin 1992] called a "regulated randomization procedure" [see Koehler & Levin 1997]. In this design, 10 participants completed 10 sessions. Initially, each participant completed a number of text sessions (the number of sessions is randomly determined). The remaining sessions were completed as hypermedia sessions. In both text and hypermedia of sessions, participants first studied the corresponding materials for 20 minutes, and then completed two sorting tasks. The first sorting task required participants to sort example word problems onto a grid. The grid afforded participants to group like problem types. The second sorting task was analogous solution strategy sort. Participants' sorts were scored according to CGI framework. For every

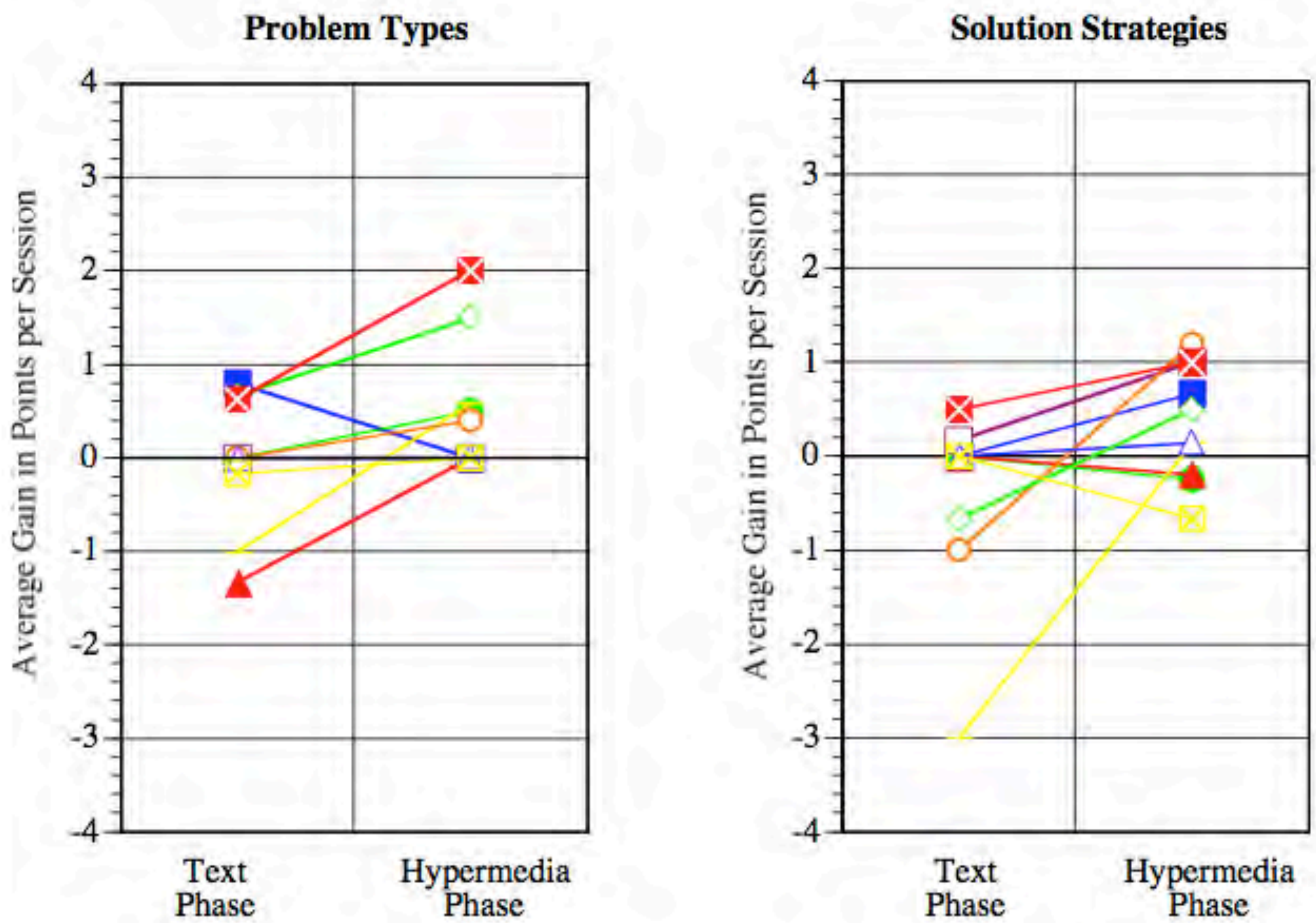

Figure 1: Participants' learning gains in text and hypermedia sessions

participant, difference scores between sessions were calculated for both measures of learning (the problem type and solution strategy sorting tasks).

[Fig. 1] displays the average difference score on problem type and solution strategy sorts for every participant during the text and hypermedia phases. Participants learned the CGI solution strategy concepts significantly faster in the hypermedia phase than in the text phase ($p < .05$). The difference between the hypermedia and text conditions was not statistically significant for the learning of problem types. However, ceiling effects made inference in the problem type sorts more problematic. The hypermedia system also recorded detailed trails of users' interactions. These records of user interaction provided useful sources of evidence in secondary analyses that help to explain the effectiveness of the HyperCGI system.

Discussion

Learning about CGI with the hypermedia system proved significantly better than learning with text. Secondary analyses suggest that this result may be attributed to several elements of the hypermedia design. First, participants criss-crossed the landscape of CGI by using the explicit criss-crossing provided by the hypermedia links for 19% of their navigational moves. They also used the implicit criss-crossing of the guided tours for another 42% of their navigational moves. Second, learning about solution strategies, a relatively ill-structured component of CGI was highly related to the amount of time participants spent on video examples (p < .05), probably because the video clips were able to convey aspects of children's strategies that were not easily conveyed in text. As expected, the examples were not as useful for learning about problem types, perhaps because the CGI framework for problem types is well-defined and therefore well-suited to text descriptions. Third, the wide variety of navigational tools afforded multiple navigational patterns that allowed for individual differences (e.g., domain expertise, hypermedia experience, field dependence). None of the resulting navigational patterns were predictive of learning. Further evidence for this claim lies in the fact that participants' navigational patterns changed over time, but did not significantly effect their learning.

This study also shows that the regulated randomization procedure may be profitably employed in media-related research. Although we used this design to make inference about learning, the design could be easily adapted to make inference about other issues as well. For example, to study the effect of different tools upon users navigation, one potential design might first introduce a set of tools (A) followed by a set of tools (B). The measures of navigational patterns could be unobtrusively collected from users' log files. Here, sound inference about effect of tools upon navigation can be made, without the added burden and expense of large number of participants. Further investigation of conceptually-based hypermedia design and of the utility of single-subject methodologies both appear warranted

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