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ABSTRACT

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The Effects of Search Tool and Cognitive Style on Performance in Hypermedia Database Searches

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Abstract

This study investigated the effects of interface tools and learner cognitive styles on performance in searches for information within a hypermedia database. The subjects, 75 students in a university ESL program, were blocked for field dependence and assigned to four treatments which differed by the search tool available. The subjects searched EarthQuest, a social studies and science hypermedia database, for facts to answer practice and posttest questions on science topics. Field-independent subjects had significantly better achievement than field-dependent subjects in both the index/find and map treatments but not in the browser or all tools treatments. The active engagement, transfer of concepts to new contexts, and high information processing demands that accompany effective use of the index, find, and map tools may explain the greater achievement by field independents. The interface design and instructional use of hypermedia databases should reflect the range of cognitive styles of users.

The Effects of Search Tool and Cognitive Style
on Performance in Hypermedia Database Searches

The use of hypermedia systems for learning and information retrieval has grown very rapidly in recent years. Hypermedia cover a wide range of applications, from online documentation and help systems to authoring tools for instruction and learning (Jonassen & Grabinger, 1990). Some educational researchers have been intrigued by the possibility that hypermedia can be structured to reflect the semantic network of a subject matter expert's knowledge and then used for instruction to help learners acquire not only knowledge but also the expert's knowledge structures (Jonassen & Wang, 1993). Others see different potentials for the use of hypermedia in education. Duchastel (1990) argues that the greatest impact will be for information retrieval, allowing easy access to the vast amount of information that will be available electronically in the very near future. In explaining his position, Duchastel stresses what he considers the essential characteristic of hypermedia: information organized in a network that provides the user with "the capability to quickly access additional information related to the information currently under consideration" (1990, p. 136).

However, accessing information from a hypermedia system is often not an easy task, especially for novices. Users may encounter a number of common problems (Hammond and Allinson, 1989). They may get lost or have difficulty gaining an overview or finding specific information. They might wander without an orienting goal or strategy, or they may find the interface tools difficult to use. Such problems have prompted research on the manner in which users interact with hypermedia.

The focus of some research has been on the effectiveness of different tools for searching hypermedia databases. Jones (1989) investigated the use of menus embedded in the text for browsing compared with indexes for searching encyclopedia articles in a hypertext system. Both success on finding facts and score on an incidental learning posttest indicated no advantage of one tool over the other. Using a hypermedia-based city guide, Hammond and Allinson (1989) studied exploratory and directed searches under five tool use conditions: hypertext links alone, with maps added, with an index added, with tours added, or with all of these tools. A posttest over factual knowledge gained from exploration and a search for specific information in the database showed no significant effect for the tool used in either task. Wright and Lickorish (1990) had learners use two hypertext databases, one with a book-like structure and the other with a hierarchical structure, which they searched by either a map or an index. To answer questions, users had to compare information from different sections in each database. The results showed no significant differences for the two search tools.

The studies reviewed above provided learners with little or no practice using the tools before engaging in search tasks. In the present study, learners received a 45-minute hands-on orientation to searching a database and a 30-minute practice search of the database. Cronbach and Snow (1977) provide theoretical and experimental support for their recommendation that study treatments should be long enough to allow learners to gain experience with instructional procedures.

Another factor which may account for differences in information retrieval from hypermedia is the individual characteristics of users. One of the most extensively researched characteristics is field dependence, a psychological construct identified and elaborated primarily through the work of H. A. Witkin and his colleagues (Goodenough, 1986). The field dependence construct describes differences of ability in

perceptual and cognitive problem solving. In tasks that require disembedding parts of a field from the overall organization of the field, field-dependent individuals will tend to experience the parts as "fused," whereas field-independent individuals tend to experience the parts as distinct from the field as an organized whole (Witkin, Oltman, Raskin, & Karp, 1971). This stylistic tendency in perception is also displayed in intellectual functions, as what is termed cognitive style. An ability to disembed simple figures from complex designs is reflected in an ability to solve a cognitive problem by isolating a critical element and using it in a different context. Thus, as Witkin and colleagues (1971) explained, a field-independent person is capable of a more analytical cognitive functioning than a field-dependent person, who uses a more global approach.

The few studies that have investigated cognitive style as a factor in use of hypermedia systems found performance differences between field independents and field dependents. Repman, Rooze, and Weller (1991) presented a hypermedia lesson on computer ethics to study the effects of advance organizers and structural organizers as a function of the cognitive style of junior high students. Different mixes of a map, an outline, and screen titles differentiated four treatments. Although field-independent learners outperformed field-dependent students in all treatments, the absence of any benefit from advance or structural organizers on the field-dependent learners was contrary to what the investigators expected.

En-route performance differences were found by Stanton and Stammers (1990) when they compared field-independent and field-dependent adults using hypertext training modules. Post-hoc classification of the users by the ways they accessed the hypertext structure indicated that the more field-dependent users tended to move from details to main points in the modules. The authors concluded that this "bottom-up" strategy reflected the tendency of field-dependent individuals to develop a mental model through hands-on experience rather than to fill in a model formulated previous to the interaction as would be expected of field-independent users.

When Jonassen and Wang (1993) investigated different methods for making structural knowledge of hypertext information accessible to learners, they observed treatment differences by cognitive style. A browser treatment used pop-up windows to identify the semantic nature of each hypertext link. A semantic selection treatment required the learner to choose the semantic type from a list at each link in order to navigate across links. A control treatment offered no structural information at the links. On a posttest recall task, field-independent learners did better in the control and semantic selection treatments and worse in the browser treatment. The authors suggested that this result reflected the preference of field-independent learners to restructure information rather than accept the structure provided by materials.

The cognitive style studies described above examined the exploratory behavior and related learning of users. In contrast, the present study set specific information retrieval tasks and focussed on search task performance.

The purpose of the present study was to investigate the effects of search tool and cognitive style on performance in hypermedia database searches. The search tool variable had four levels: browser, index/find, map, and all tools. The cognitive style variable had two levels: field independent and field dependent. Performance was measured on searches in the database to find specific information. Besides search achievement, patterns of tool use were of interest in this study. Also, attitudes of the learners toward the tasks were obtained.

It was hypothesized that the four treatments would differentiate between learners with analytical (field independent) and global (field dependent) styles of cognitive processing. Therefore, interaction of the treatment search tools with the cognitive styles of the learners was expected. The browser, map, and all tools treatments were expected to be used with similar effectiveness by field-independent and field-dependent learners. However, the index and find tools were expected to be more advantageous than other tools for field-independent learners and to be less useful for field-dependent learners.

This hypothesis is based on the comparatively greater benefit for field dependent learners when material is encountered in a structured or organized manner (Davis, 1991). The browser and map tools would provide a more consistently structured user-content interface than would the index and find tools. Use of the index and find tools would involve disembedding words and concepts from their context at a screen and transferring them to other contexts at other screens. The expectation that field-dependent learners would not perform better than field-independent learners in any treatment reflects the results of cognitive style research, which Davis (1991) found provided no evidence of an advantage for field-dependent learners except when the context has social relevance.

Method

Subjects

Subjects were 75 adult students (40 males, 35 females) enrolled in an intensive preadmission English as a second language (ESL) program at a large southwestern university. These students came from more than a dozen different countries. Their reading comprehension level in English was two semesters or less below American freshman student proficiency.

Materials

Materials in this study included a HyperCard database, a print-based orientation packet, a print-based practice packet, and the Group Embedded Figures Test.

The content material for the study was a HyperCard database called EarthQuest (Stevens & Smith, 1990). This published hypermedia program is designed for secondary social studies and science instruction. The content is arranged hierarchically under five major headings: Earth (an earth science focus on planets, land, water, air, and life), Journey (a historical approach to invention and politics), Environment (interrelationships and ecological issues for land, water, air, and life), & World Tour (a geographical overview of nations by continent). Information is presented on over 80 screens by text, graphics, animation, and sound. Many of these screens include pop-up windows with scrolling text. EarthQuest provides five basic tools for navigation and search within the database. Graphic/text buttons on each screen can be clicked to move to the content they represent. Browser icons can be used to navigate between any contiguous screens at the same level and up or down the content hierarchy. An index lists the contents of the database as one- or twoword topics which can be selected to reach the content screens for those topics. A find feature searches the database for typed text strings. Maps display a hierarchical arrangement of the content and allow searching by category,

subcategory, and individual screen topic. Each of these five tools can be used to reach any content screen in the database.

EarthQuest was modified for three of the four treatments in this study. The browser treatment had the index, find, and map tools disabled. The index/find treatment had the browser and map tools disabled. The map treatment had the browser, index, and find tools disabled. The all tools treatment used an unmodified version of EarthQuest.

The orientation packet contained handout directions to familiarize learners with the search tools. The directions explained how to use each tool to conduct searches of the database to find specific information.

The practice packet contained handouts giving practice search directions and questions. Each of the five search questions asked for the name of the database screen where information was located as well as the answer found there. The first three questions required searches for isolated facts. The other two were cause/effect and main point/support questions that each required information from two screens. Some of the search questions provided hints about options selection. One of the fact-finding questions was, "Living things are found only in a very thin layer of the Earth's crust. How thick is that layer?" The cause/effect question, along with directions for it, was "Land can move and change shape, such as to make mountains and valleys. What are two causes of this kind of change? (Hint: Play movies.) Get your answers from two screens."

The Group Embedded Figures Test (GEFT) (Witkin, Oltman, Raskin, & Karp, 1971) was used to indicate the cognitive style of each learner in the study. The GEFT measures the ability to locate a simple figure within a larger complex figure which has been designed to obscure or embed the simple figure. A low score on this timed group-administered test indicates perceptual field dependence, whereas a high score indicates perceptual field independence. In broader terms, the GEFT assesses a global versus analytical dimension of cognitive style.

Procedures

Instruction took place during two 75-minute class sessions for each of six classes within a five-day period. The students were asked to volunteer their participation in a study using a computer program in the ESL computer lab. Their incentive was a daily class activity grade for each session.

The GEFT was administered to the participants at the start of the first session. Each learner then received an orientation packet. Using an overhead computer screen display of EarthQuest, the investigator led the learners through the orientation directions while the learners performed searches in the database at their individual computers. During this 45-minute orientation, all learners used an unmodified version of EarthQuest.

Before the second session, the GEFT scores were used to block the learners for assignment to the treatment groups. For this blocking, the learners were designated as field dependent if they scored from 0 to 9 on the GEFT ($n = 31$) or as field independent if they scored from 10 to 18 on the GEFT ($n = 44$). This grouping was based on the bimodal shape of the GEFT score distribution, which indicated a dichotomy of the learners. Equal numbers of learners were randomly assigned to each treatment: All Tools, Browser, Index/Find, and Map.

For the second session, the learners were assigned to their respective treatment versions of EarthQuest. During the 30-minute search practice, learners used the practice packet to search the database with their assigned treatment tools. They

received feedback by turning to the following page in the handout, where the answer was given above the next question.

After the practice, a posttest was administered. The learners were allotted 30 minutes to search EarthQuest for answers to the posttest questions using their assigned tools. At the end of the second session, the learners completed an attitude questionnaire.

Criterion Measures

The dependent variables in this study were achievement on posttest searches, tool use during posttest searches, and learner attitudes.

The posttest was parallel in format to the practice searches but from a different content area in the database. Each answer received one point if the information was correct and another point if the location of that information in the database was correct, to give a total of 14 possible points. Identification of the location increased the probability that learners would actually perform searches in order to answer the questions rather than rely on their prior knowledge of the content. The Cronbach alpha reliability coefficient of the posttest was .66.

Tool use during the posttest searches was recorded for each learner by means of a tracking script added to the EarthQuest program. This script captured data on the tool the learner selected to navigate to each screen and the time when each screen was accessed. These data were compiled to give both the number of screens accessed using each tool and the time spent at those screens. The four measures for patterns of tool use were number of screens accessed using treatment tools, number of screens accessed using graphic/text buttons, time at screens accessed using treatment tools, and time at screens accessed using graphic/text buttons.

Attitudinal data was obtained by a 4-point Likert-type questionnaire consisting of 12 items. The questions asked learners to respond to statements about the value of the lesson and their enjoyment of it, the ease of use of the database, and their understanding of the directions and questions. Two questions specific to each treatment asked about the usefulness and ease of use of the tools assigned for that treatment. The alpha reliability of the questionnaire was .85.

Design and Data Analysis

A 4 X 2 (search tool X cognitive style) posttest-only experimental design was used, with random assignment to treatment groups after blocking by cognitive style.

Due to unequal cell sizes in the study design, homogeneity of variance for the posttest scores was a concern. The Bartlett-Box F test (Glass & Hopkins, 1984) indicated that the scores were homogeneous in variance among cell groups ($p > .25$).

An alpha of .05 was used for all statistical tests. Posttest achievement was analyzed with ANOVA; tool use and attitudinal data were analyzed with MANOVA. If multivariate significance was found on analysis of the tool use and attitudinal data, univariate tests were then performed. For any significant main effects found for the search tool variable, Tukey multiple comparisons followed.

Results

Achievement

Table 1 gives mean posttest scores by level of search tool and cognitive style. The mean posttest scores by level of search tool were 7.37 for the all tools group,

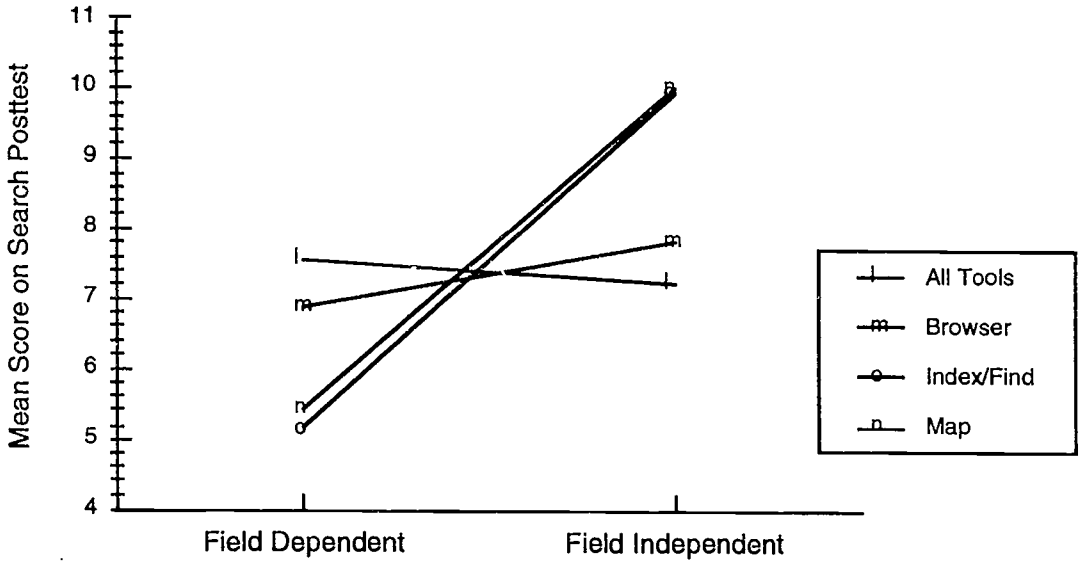
7.39 for the browser group, 8.16 for the index/find group, and 8.32 for the map group. The mean scores by level of cognitive style were 6.35 for the field dependent group and 8.84 for the field independent group.

Table 1
Search Test Scores by Search Tool and Cognitive Style

Cognitive Style	Search Tool				
	All	Browser	Index/Find	Map	Total
Field Dependent					
M	7.56	6.88	5.14	5.43	6.35
SD	2.83	3.18	3.29	3.36	3.16
Field Independent					
M	7.20	7.80	9.92	10.00	8.84
SD	3.99	2.82	2.61	1.59	3.00
Total					
M	7.37	7.39	8.16	8.32	7.83
SD	3.40	2.93	3.66	3.23	3.28

ANOVA revealed a significant interaction between search tool and cognitive style, $F(3,67) = 3.48$, $p < .05$, ES = .37. This interaction is illustrated in Figure 1. A simple main effects test (Ferguson & Takane, 1989) suggested that within the index/find treatment, fieldindependent learners ($M = 9.92$) performed significantly better than field-dependent learners ($M = 5.14$), $F(1,67) = 12.27$, $p < .001$, ES = .70); within the map treatment, fieldindependent learners ($M = 10.00$) also performed significantly better than field-dependent learners ($M = 5.43$), $F(1,67) = 11.74$, $p < .001$, ES = .68. No other significant differences were found when simple main effects tests were conducted.

Figure 1. Effects of search tool and cognitive style on search test achievement.



ANOVA also indicated that cognitive style was significantly related to achievement, $F(1,67) = 12.65$, $p < .001$, ES = .41. Field-independent learners performed significantly better on the posttest than field-dependent learners. ANOVA did not reveal a significant main effect for search tool treatment.

Tool Use

MANOVA revealed that search tool treatment had a significant effect on tool use, $F(12,108) = 3.85$, $p < .001$. Univariate analyses indicated that differences occurred for the number of screens accessed using treatment tools, $F(3,67) = 8.21$, $p < .001$, ES = .57, and for the number of screens accessed using graphic/text buttons, $F(3,67) = 4.68$, $p < .01$, ES = .43.

Tukey multiple comparison tests suggested that learners in the browser treatment (M = 32.37) significantly accessed more screens using their treatment tool than did learners in the index/find treatment (M = 8.57) and in the all tools treatment (M = 14.33). Tukey multiple comparison tests also indicated that learners in the browser treatment (M = 38.12) significantly accessed more screens using the graphic/text buttons than did learners in the index/find treatment (M = 14.86).

MANOVA also revealed that cognitive style was significantly related to tool use $F(4,51) = 3.11$, $p < .05$. Univariate analyses indicated that differences occurred for the number of screens accessed using treatment tools, $F(1,67) = 14.13$, $p < .001$, ES = .43. Fieldindependent learners (M = 27.86) significantly accessed more screens than did fielddependent learners (M = 12.93).

Learner Attitudes

Three of the 75 learners were not included in the analysis of questionnaire data due to incomplete responses or unreturned forms.

Data on learner attitudes were measured on a 1 to 4 scale with 1 as "strongly agree" and 4 as "strongly disagree." Learner attitude results indicated a general liking for both the program and the tasks, with a mean response of 2.16. The highest response (M = 1.70) was to the statement, "EarthQuest is a good program." The lowest response (M = 2.65) was to the statement, "I had enough time to answer the questions."

MANOVA revealed that cognitive style had a significant relationship with attitude, $F(12,43) = 2.60$, $p < .05$. Univariate analyses indicated that significant differences occurred for two of the 12 items. Field-independent learners (M = 1.93) responded more positively than the field-dependent learners (M = 2.33) to the statement that the assigned treatment tool "was useful for finding the answers to the questions," $F(1,64) = 5.77$, $p < .05$, $ES = .28$. However, field-dependent learners (M = 1.44) were more positive than the field-independent learners to the statement, "EarthQuest is a good program," (M = 1.89), $F(1,64) = 4.55$, $p < .05$, $ES = .25$.

Discussion

The purpose of this study was to investigate the effects of search tool and cognitive style on performance in hypermedia database searches. Learners assigned to one of four interface tool treatments searched for specific information in the EarthQuest database. Cognitive style was defined in terms of field dependence, as measured by the GEFT. The results of this study support the hypothesis for an interaction of search tool with cognitive style.

As expected, the search achievement in the index/find treatment was significantly better for the field-independent learners than for the field-dependent learners. This superiority may be a reflection of "more active approaches to learning, such as hypothesis testing and employment of verbal mediators" (Goodenough, 1976, p. 676), approaches which a variety of studies have associated with field independence (Witkin, Moore, Goodenough, & Cox, 1977). In order to navigate from screen to screen in EarthQuest when using the index and find tools, the learners had to physically select a word or phrase by either typing it into the find dialog box or choosing it at the index. When the screen accessed by this action was in a different section of the database, the learners encountered a new context. It therefore appears likely that active approaches, such as hypothesis testing or the use of verbal mediators, were important for searches employing the index and find tools. Fieldindependent learners, being more inclined to engage in hypothesis testing or to use verbal mediators, would be expected to have an advantage when using the index and find tools.

The search achievement results also confirmed the expectation of no significant difference by cognitive style in the browser and all tools treatments. Cognitive style research offers an explanation for this. Field-dependent individuals tend to use "more intuitive spectator approaches" to learning (Goodenough, 1976, p. 676). When searches in EarthQuest were performed using the browser tool, a click of the browser icon accessed a contiguous screen at the same level, higher, or lower in the content hierarchy. Often there was no need to enter a different section of the database. This less active style of interaction would benefit field-dependent learners.

The similarity of the all tools treatment results to those of the browser treatment for search achievement can be understood from the patterns of tool selection revealed by the tracking data. When the all tools learners accessed screens by treatment tool, 70% of the time they used the browser, compared with 28% for the index and find tools and 2% for the map. Since the all tools learners predominantly used the browser, it is not surprising that their performance was similar to that of the browser learners.

Search achievement results for the map treatment were contrary to expectation. The field-independent learners assigned to use the map tool outperformed the field-dependent learners under this treatment with a difference and an effect size close to those found for the index/find treatment. The hypothesis had predicted search achievement of the map users similar to that of the browser users. It was assumed that using the maps would provide the learners with a structured interface that could accommodate the more global approach of field-dependent learners. However, unlike the other tools, the maps were not available on every screen. The learners had to access them on separate map screens. To move through the map hierarchy from main sections to subsections in order to access individual screens, at least one additional map screen had to be selected. The map screens thereby took the learners out of the context of a content screen. Field-independent learners, with their greater ability to transfer concepts to new contexts, appear to have an advantage at this kind of map interface.

Additional support for these explanations comes from information processing research on cognitive style differences. In a review of these studies, Davis (1991) concluded that little or no difference was found between field-independent and field-dependent learners when a limited amount of information was processed. However, field-independent learners were consistently more efficient in situations with higher information-processing demands. Reflecting Marchionini's observation that "it takes less cognitive load to browse than it does to plan and conduct an analytical, optimized search" (1987, p. 70), in the present study it appeared that the browser tool placed less information processing demands on learners than the other tools.

The results for patterns of tool use revealed that while using their treatment tools, the field independents accessed more screens than did the field dependents. This adds support to the suggestion that the field-independent learners were more actively engaged when searching the database than were the field-dependent learners.

The attitudinal results indicate that EarthQuest was generally well-received, although cognitive style differences appeared in the attitude questionnaire responses. The fielddependent learners strongly agreed that EarthQuest was a good program; the fieldindependent learners were less positive, but also agreed that it was good. Locus of control may be an important factor in this difference in attitude. Field-independent learners tend to be more internally motivated and less influenced by external goals, compared with fielddependent learners (Witkin et al., 1977). Locus of control could account for differences in attitude found by Small and Grabowski (1992) in student use of a hypermedia system. Although all of the field-dependent subjects in that study were satisfied with only the hypermedia lessons, most of the more field-independent subjects said they would probably consult other sources as well. In the present study, the field-independent learners may have considered the EarthQuest lesson an inadequate way to achieve their language learning goals, whereas the field-dependent learners appeared to be more accepting of the lesson as part of their classwork in English.

The results of this study have implications for the design of hypermedia and its use in the classroom. Decisions about which interface tools to provide for database search and information retrieval should take into account the cognitive styles of users. Tools such as a browser, which can be used effectively without placing high information processing demands on the user, should be made available for field-dependent individuals. Index, text-string find, and other tools that allow more analytical and optimized searches would provide fieldindependent users with an efficient method for information retrieval. In a variety of settings, students with different cognitive styles could learn more, and perhaps be better motivated, if activities involving information retrieval accommodated the cognitive processing approaches of those students.

An avenue of future research on cognitive style factors in the use of hypermedia could involve the formulation of criteria for interface tool design. Hutchins, Hollan, and Norman (1986) use the term direct engagement to identify the nature of user interaction with computers. When there is greater direct engagement, the computer interface becomes more transparent and the user more involved in the illusion of acting directly upon the objects in the task domain. Hutchins and colleagues suggest that this feeling of directness is "inversely proportional to the amount of cognitive effort it takes to manipulate and evaluate a system" (1986, p. 95). Perhaps a measure of direct engagement could be applied to the tools used in hypermedia systems. A tool which provided greater direct engagement would lessen the cognitive effort, or information processing demands, of the learner and would especially benefit those with a more field-dependent cognitive style.

The current growth in the use of hypermedia both in education and communications suggests that it deserves the attention of educational technologists. Jonassen and Grabinger (1990) envision the possibility of an extensive impact of hypermedia on our lives that would require a new form of literacy: "If large amounts of our reading in the future will be by unguided and unconstrained electronic text, new strategies (a hypermedia literacy) will be needed" (p. 21). If our work as educational technologists is to include facilitating the use of new information forms, we need to consider how cognitive style and other individual characteristics affect the performance of learners.

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