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# Assessing Spatial Navigation Tools with Instructional Hypermedia for Cognitive Science

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**Abstract:** We investigated the influence of spatial visualization, spatial reasoning, and environmental cognition skills on students' use of instructional hypermedia navigation tools. Forty undergraduate cognitive science students were randomly assigned to one of two hypermedia system conditions: a map-like navigation tool ("spatial" representation) or a menu-like navigation tool ("less spatial"). All students performed a searching activity, then browsed freely through the system. Students then commented on their perceptions of the system and drew concept maps of the contents. Regression analyses indicate that performance with the map-like navigation tool is positively correlated with environmental cognition, whereas performance with the menu-like navigation tool is positively correlated with spatial visualization and reasoning. The general findings suggest that spatial navigation tools should be incorporated into instructional hypermedia with less spatial navigation methods to complement students' spatial cognitive abilities.

## Introduction

The past two decades have seen a remarkable increase in the use of computers in education. Hypermedia is in the early stages of development, and the focus of educators on the instructional potential of hypermedia systems has generated a host of questions regarding the organization of, and access to, information in these systems. This paper presents results from an investigation into the relationship between spatial abilities and the use of instructional hypermedia systems. If, as is commonly assumed, information in a hypermedia system is represented spatially, then successful navigation through, and integration of, the information will likely be related to a student's ability to mentally represent and manipulate an "information space." The results of this study provide evidence for the influence of hypermedia navigation on conceptual structure and, it is hoped, will guide future implementation of navigation tools in instructional hypermedia systems.

### Spatial Ability and Navigation in Instructional Hypermedia

Authoring systems such as Hypercard have resulted in powerful, flexible tools and have made possible the design of instructional materials using multiple links within and between documents and media. This flexibility of structure allows students to explore material in a nonlinear, interactive, fashion and can make these applications effective tools in an educational environment [McAleese 1989]. Instructional hypermedia applications are still so new that their effectiveness as teaching tools is not well documented. Jonassen outlines three problems commonly associated with hypermedia [Jonassen 1989]: (1) students may get lost in the network of information due to unsuitable links or navigation methods, (2) students may not be able to construct a conceptual overview or access all parts of the information, (3) students may have difficulty finding information or making the correct path choices.

Information structures and tools have been developed to aid students in both orientation ("Where am I?") and navigation ("How do I get to...?") while following a path through an instructional hypermedia application. A recent line of research investigates the "navigation problem" of whether students are able to take advantage of the learning potential offered by the flexibility of hypermedia systems or become "lost in hyperspace." A solution to the navigation problem that appears to be gaining in favor is to provide several general navigation tools, including: backtracking or history mechanisms, overview diagrams or maps showing various levels of detail, landmarks or prominent nodes, indexes, and on-line guidance [Nielsen 1990].

A student's ability to take advantage of such hypermedia structures and tools is likely to be related to their ability to represent the hypermedia environment spatially (cf., [McGrath 1992]). We might expect that search and navigation skills required in hypermedia systems will exhibit a high correlation with environmental cognition (e.g., sense of direction, path-finding), perhaps even more so than with traditional psychometric measures of spatial ability [Pearson & Ialongo 1986]. It has been suggested that students interacting in a hypermedia environment attempt to create cognitive representations, or "maps," of hypertext structures similar to those reported in the literature on environmental navigation [Edwards & Hardman 1990] . Given the analogy between navigating in a physical environment and in a hypermedia environment, it seems plausible that a spatial cognitive representation of a hypertext would manifest itself.

### Conceptual vs. Spatial Navigation

This study will help to determine which information structures and navigation tools can be effectively used by students. It has been suggested that providing overly explicit spatial representations of a hypermedia environment—e.g., in the form of overview maps—could interfere with a student's attempts to construct their own mental map of the information [Stanton, Taylor & Tweedie 1992]. If navigation in a hypermedia environment is primarily conceptual, the apparent structure of a spatial map may be misleading. However, if navigation is primarily spatial—that is, following routes and landmarks analogous to naturalistic environmental navigation—a map-like navigation tool may reduce the cognitive overload required to form a mental representation of the system's structure.

If the representation of a hypermedia environment is spatial, students varying in their ability to represent their environment spatially should differ in their performance and in how well they are able to use various navigation tools in a hypermedia environment. In this study, the following hypotheses are addressed using a hypermedia environment incorporating either a map-like or menu-like navigation tool: (1) students with differing spatial skills will differ in their representations of and organizations of connections among nodes within the hypermedia environment, and (2) students with differing spatial skills will differ in their use of navigation tools and navigation strategy.

## Method

### Subjects

Forty undergraduates (27 men and 13 women) from the University of California, Berkeley, participated in this experiment as part of a laboratory assignment in an introductory Cognitive Science course. The students ranged from 17 to 33 years of age. All students had some experience with computers, though they varied in their experience with hypermedia applications.

### Design and General Procedure

The participants were randomly assigned to one of two hypermedia conditions: map or menu. The content and structure of the information in the two systems was identical, but the means of navigating through the two systems varied. Subjects spent about four hours on the activities, as described below.

### Materials and Specific Procedures

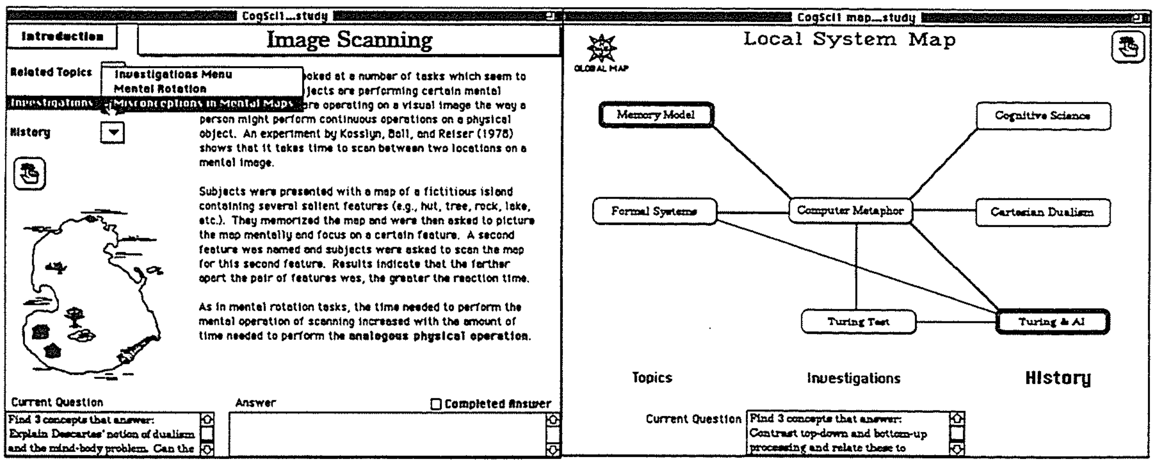
#### *Hypermedia Activities and Stack Design*

Students worked with the "CogSci" review hypermedia stack for 40 minutes during a laboratory section. For the first 25 minutes, they engaged in a search task, answering a series of Cognitive Science questions that required the integration of the material in the stack. For the last 15 minutes, they were permitted to browse freely through the information in the stack. After their interaction with the review stack, students were given as much time as they needed to complete a questionnaire reflecting on their activities.

The hypermedia environment was created using Hypercard 2.2 with color tools (the program will be referred to as a "stack"). The hypermedia environment is designed to help students identify themes running through the Cognitive Science course by linking together diverse topics, methods, and theoretical background. Two separate stacks were designed for this study: one using diagrammatic "maps" for moving from one screen of information (or "card") to another, and one using "menus" for such movement.

The menu stack has three principal menus, each with different emphases, to serve as "landmark" nodes: Topics, Investigations, and History. The individual cards (thirty-three cards of information) in the menu stack are identical to those in the map stack except for the navigation tools in the upper left corner of the screen [see Fig. 1]. Students use local "pop-up" menus either to return to a principal menu or to select a related card to move to.

The map stack has a global system map that serves as the "landmark" node. From the global map, students can move to any card in the system (including local maps). The local maps graphically show the links to all the cards related to a particular card (i.e., those that appear in the pop-up menus in the menu stack) and students use the local maps to move to a new card [see Fig. 1].




(a) (b)

**Figure 1.** (a) *Image Scanning* "card" from the menu stack with "pop-up" menus used to select related ("linked") topics, (b) Local system map for *Computer Metaphor* from the map stack.

### *Environmental Cognition Tasks*

Students were led in small groups through the third floor of a campus building, and their attention was directed to fourteen sites along the path. They were then given sufficient time to complete a questionnaire highlighting knowledge about the distance and direction of places in relation to each other (indicating configural knowledge; cf., [Kozlowski & Bryant 1977]). Students were also asked to draw their path on a two-dimensional map of the environment (indicating route knowledge), and to identify the locations of the fourteen sites on their path (indicating landmark location knowledge; cf., [Pearson & Ialongo 1986]).

### *Psychometric Spatial Cognition Tasks*

Measures of spatial cognition generally measure two primary facets of spatial cognition: spatial reasoning (about relations) and spatial visualization. The Space Thinking (Flags) two-dimensional mental rotation test served to test spatial reasoning [Thurstone & Jeffrey 1959]. Spatial visualization was tested with a two-dimensional Minnesota Paper Form Board Test [Likert & Quasha 1970] and a three-dimensional surface development problem set from the Differential Aptitude Test [Bennett, Seashore & Wesman 1974].

## Results

For purposes of visualizing the results, students were divided into high- and low-spatial groups based upon a median score that spanned the three spatial ability measures. The total psychometric spatial score (three tests combined; max possible = 292, median = 150) and the total environmental cognition score (two tests combined; max possible = 32, median = 20) were proportionally combined to produce a general spatial cognition score (max possible = 548, median = 306). The task in which students retraced their path on a map was not included in the environmental score due to a ceiling effect. There is no significant correlation between any of the spatial scores and students' prior knowledge of course material, as reported on the self-questionnaire, ($r = .19$, $p > .10$) or course performance, as assessed by course grades ($r = .238$, $p > .10$); therefore, observed differences cannot be attributed merely to student mastery of the stack contents prior to the study.

### Correlations Among Spatial Measures

The two separate environmental cognition measures were highly correlated ($r$=.365, $p < .05$) as were the psychometric two-dimensional and three-dimensional spatial visualization scores ($r$=.44, $p$<.05). The psychometric 2-D and 3-D visualization measures were also significantly correlated with the psychometric spatial reasoning measure ($r$=.34 and $r$=.362 respectively, $p < .05$). However, neither of the environmental cognition measures are significantly correlated with any of three psychometric spatial ability measures.

### Hypermedia Questionnaire

Students in the map condition reported learning more from the hypermedia program and considered it more useful than students in the menu condition (mean values of 4.71 vs. 4.16; marginally significant at $p < .10$). However, there is no significant difference in how they perceived the utility of the tools associated with their systems (e.g., global/local maps in the map condition and menus/pop-up card links in the menu condition). There is an interaction between general spatial ability and stack condition on a "lostness" measure ($F$=5.64, $p$<.05; [see Fig. 2]). Students higher in spatial ability were more likely to report a feeling of disorientation while navigating through the menu-like system.

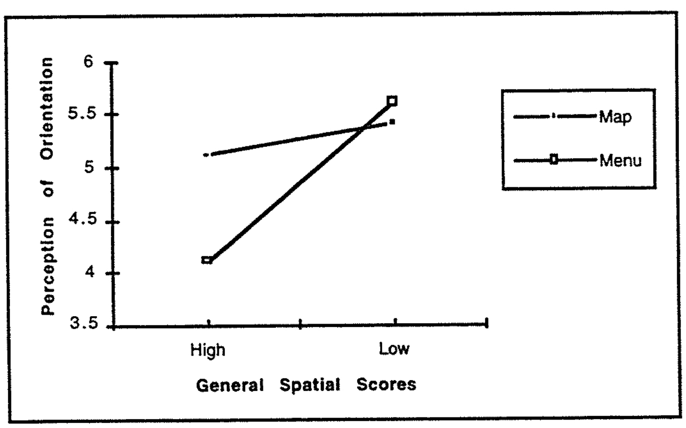



**Figure 2.** Perception of orientation ("non-lostness") varies with hypermedia stack condition and general spatial ability. (Based on a seven-point Likert scale; the higher the rating, the more secure students felt in their orientation.)

### Hypermedia Logs

There is an interaction between spatial ability and use of a particular navigation tool for the number of questions answered ($F = 6.83$, $p < .05$); menu students higher in spatial ability worked through as many questions as (both high and low spatial ability) students in the map condition [see Fig. 3]. There is also a difference in the number of cards visited by students in each system. Menu students who were higher in spatial ability tended to visit more cards, and more different cards, in both the search and browse modes [see Fig. 4]. In accord with the greater number of cards that they visited, high-spatial students in the menu condition used significantly more card links (pop-up menus) than low-spatial students ($r = .478, p < .05$). They also used the History menu more often for navigation, but they did not differ in their use of the Topics or Investigations menus ($r = .467, p < .05$). Two main topics on the first question—Computer Metaphor and Cartesian Dualism—were listed on the History menu; and, while high-spatial students also used this menu slightly more in the browse mode (e.g., when not answering the questions), this may be due to familiarity gained in the search mode.

In the map condition, spatial ability was significantly related to the preferred use of navigation tools. Navigation via the global map is negatively correlated with spatial ability ($r = -.477, p < .05$). Further, while all students used the local maps for navigation equally often, the number of *different* local maps visited is positively correlated with spatial ability ($r = .526, p < .05$; [see Fig. 5]).

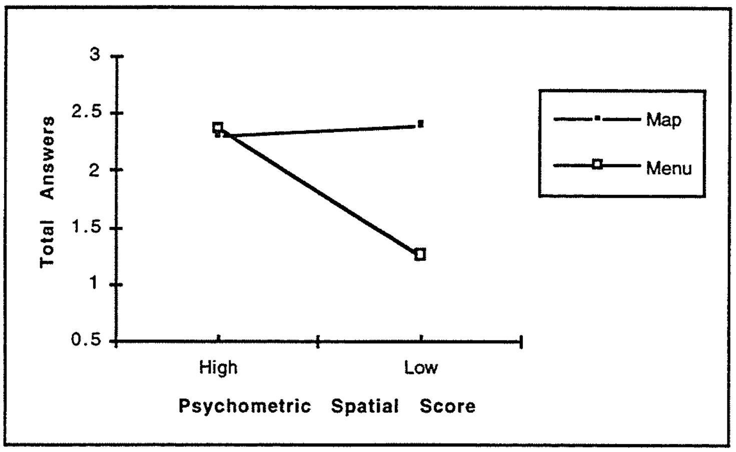



**Figure 3.** Low-spatial students provide answers for fewer questions in the menu condition.

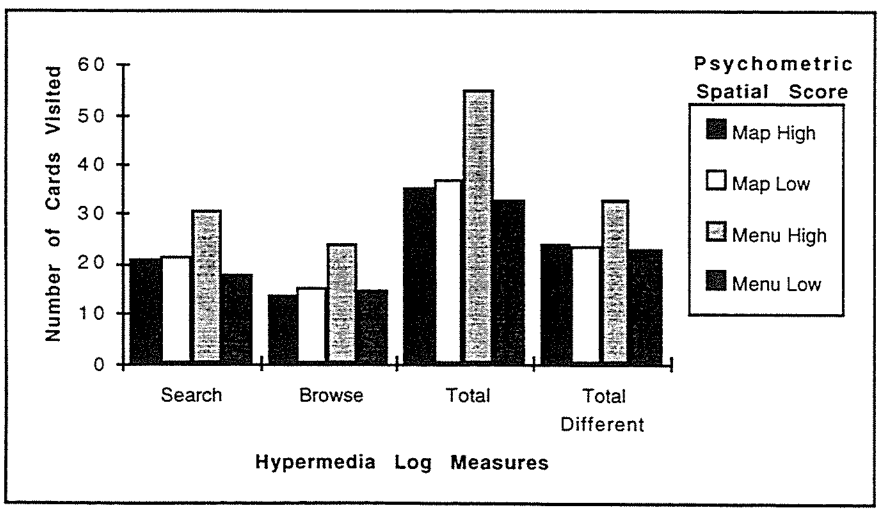



**Figure 4.** High-spatial students visit more cards in the menu condition.

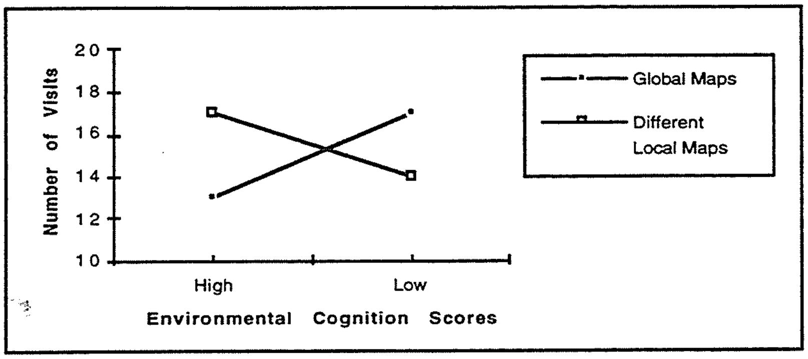



**Figure 5.** Low-spatial students rely more on the global map for navigation in the map condition. The reverse is true for high-spatial students.

## Concept Maps

Students in the menu condition used more subgraphs in their concept maps than students in the map condition (mean of 4.05 vs. 2.45; r = .328, p < .05). Students included the same number of concepts in their concept maps; however, there is an interaction between general spatial ability and stack condition in the number of links that students used to connect these concepts ($F$=9.21, $p$<.05). High-spatial students in the menu condition represented more primary and secondary links in their concept maps ($r$ = .44, $p$ < .05); however, their proportion of actual stack links is not higher than the other students' proportion ([see Fig. 6]; primary links exist when one can jump directly from one concept to another, and secondary links exist when two concepts share a primary link with a third concept, but not with each other).

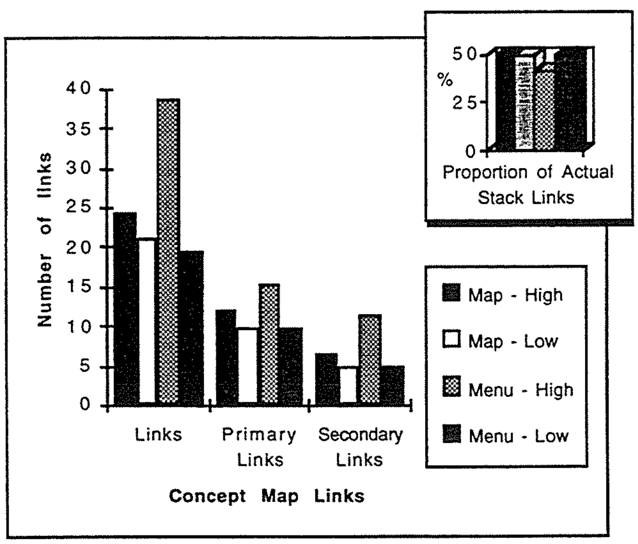



**Figure 6.** High-spatial students in the menu condition include more links in their concept maps; however, their proportion of actual stack links remains consistent with other students' proportions (see inset chart).

## Psychometric Spatial Ability vs. Environmental Cognition

In general, the observed differences in performance were correlated with a specific spatial skill depending upon the navigation method. In the menu condition, the differences in performance observed in the questionnaire responses, logs, and concept maps are more closely correlated with psychometric spatial ability measures than with environmental cognition scores. Differences in navigation behavior with the map hypermedia system are, by contrast, more highly correlated with the map students' environmental cognition scores.

## General Discussion

Hypermedia environments that are systematically designed in accordance with a theory of how the information will be processed, mentally represented, and later used will be easier to work with and afford greater educational benefits [Shapiro & Diehl 1994]. Although elements of general theories of cognition can be linked to broad design features of instructional hypermedia (e.g., learner control, multiple representations, scaffolded interaction), the design of specific support structures and guidance tools should be selectively informed by research focusing on developments in specific areas of cognition such as memory, strategy use, metacognition, language, motivation, spatial ability, and problem solving.

### Spatial Cognition and Navigation in Hypermedia

A hypermedia environment is generally taken to be spatial; if this were true, it would appear that much of our knowledge about spatial cognition and navigation in the real world could be applied to the design of information structures and navigation tools that can prevent learners from getting "lost in hyperspace." This paper presents results from an investigation into the relationship between various spatial abilities and the use of instructional hypermedia systems. Measures of psychometric spatial ability and environmental cognition were found to be partially, but not significantly, correlated. The general findings of this study indicate that there is a relationship between general spatial ability (as measured by both psychometric spatial tests and environmental cognition tasks) and how students perceive and use hypermedia navigation tools, but the particular influence of spatial visualization/reasoning and environmental cognition on student performance with hypermedia systems may depend upon the specific navigational tools and information structures represented in the system's interface.

Differences in performance were correlated with a specific spatial skill depending upon the navigation method. When working with the menu-like hypermedia system, differences in spatial visualization and reasoning appeared to influence student performance more than differences in environmental cognition. This may be due to the fact that no structured graphic visualization for the menu system was provided, and it was necessary that students construct their own cognitive map of the connections among the information in the system. Students with less spatial visualization skills appeared to have more difficulty in integrating the information in the stack; they provided fewer answers to questions than any other students, while visiting as many cards. When working with the map-like hypermedia system, differences in environmental cognition appeared to influence student performance more than differences in spatial visualization. In this case, a two-dimensional spatial representation of the system's interconnections was provided, but students used various strategies to take advantage of the tool.

Students in the map condition reported that they learned more from the program even though the utility of the navigation tools was reported to be similar across the two conditions. However, the navigation tools were the only differences between the two stack conditions; therefore, it appears that the navigation method influenced students' perceptions of the hypermedia environment. This influence is reflected in the self-reported ratings of "lostness." While searching or browsing through the menu-like hypermedia environment, students with high-spatial ability were more likely to report a feeling of not knowing where they were in relation to other information—or not knowing how to get to some information. This disorientation may result from the greater number of cards that these students visited (more than any other subgroup of students); that is, this group of students may have felt less secure in the knowledge of the system structure and how to navigate it because they had to construct a much larger mental map of the system's contents. However, these students also relied more on the primary menus for navigation than did the low-spatial students in this stack condition. So, when using a system with high-cognitive overhead (i.e., menu for spatial guidance) students with high-spatial ability appear to seek out navigation tools and information structures that are more structural in nature to aid them in constructing a cognitive representation of the environment.

### Summary

The findings from this study suggest that the use of graphical map-like navigation tools in instructional hypermedia influences the perception of the system and the interaction with the system for students varying in spatial ability. Students using map-like navigation tools developed a more integrated representation of the material in the system; their concept maps of the system contents were more connected across topic areas and they answered more integrative questions than low spatial ability students working with less spatial navigation tools. Students with higher spatial ability were less directed in their use of the less-spatial, menu-like, hypermedia system; they visited more cards but did not answer more questions. This may indicate the use of a more spatial representation of a hypermedia system with map-like navigation tools. It appears from this analysis that a student's ability to take advantage of hypermedia navigation tools is in some way related to their ability to represent the environment spatially. Systems using maps to structure the navigation may be especially useful for students with high-spatial skills who seek a spatial structure to the information. However, students with low-spatial skills seem equally able to take advantage of the structural benefits provided by a navigation map. In fact, students with lower spatial ability were *more* successful in task-oriented activities (i.e., answering integrative questions) when working with the more graphically represented hypermedia environment. These findings suggest that spatial navigation methods should be incorporated into menu-like instructional hypermedia systems to complement student spatial cognitive abilities.

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