A Study of the Relationship Between Cognitive Ability and Information Searching Performance

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Abstract

The purpose of this study was to develop a framework for predicting searching performance through an understanding of how cognitive ability relates to searching process and outcome. Specifically, this study examined the relationship between spatial visualization, logical reasoning, integrative reasoning, and information searching process and outcome. Information searching process was assessed by seven search process indicators: (1) search command selection; (2) combination of search commands; (3) application of Boolean logic; (4) application of truncation; (5) use of limit search function; (6) number of search statements; and (7) number of search errors made. Searching outcome was assessed by the number of correct answers to search questions. Subjects first took three standardized cognitive tests that measured cognitive abilities, and performed online catalog searching in response to seven information search questions. The searches were logged using Lotus ScreenCam, and reviewed for the analysis. Factor analysis was used to find underlying structures of the seven search process variables. Multiple regression analysis was applied to examine the predictive power of three cognitive variables on three extracted factors, and search outcome. Results of the data analysis showed that individual differences in logical reasoning could predict information searching process and outcome.

Key Words : cognitive ability, information searching, searching performance, spatial visualization, logical reasoning, integrative reasoning

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Ⅰ. Introduction

The purpose of this study was to develop a framework for predicting searching performance through an understanding of how cognitive abilities related to information searching performance. Specifically, the objective of this study was to determine the relationship of spatial visualization, logical inductive reasoning, and integrative process reasoning to information searching process and outcome. This study is intended to answer the following research questions relating to information searching performance.

1. Is there a relationship between spatial visualization and information searching performance?
2. Is there a relationship between logical inductive reasoning and information searching performance?
3. Is there a relationship between integrative process reasoning and information searching performance?

Ⅱ. Cognitive Demands of Information Searching

Cognitive processes involved in information searching are complex. However, very little is known about the nature of cognitive processes which take place in order to accomplish searching tasks. Several researchers suggest that searching skill is composed of many different skills. For example, Ellis proposed a "cognitive paradigm" as a framework for understanding the cognitive demands of information searching.[1] It is assumed that information system designers must take into account the abilities of users. The individual differences influence searches for information and thus are relevant considerations for the design of systems. In particular, these abilities can be viewed as resources that are used by individuals as they complete the tasks that lead them to become informed.

There has been a certain amount of investigation into the effects of individual differences on library and information searching. Allen investigated the effects of

1) Ellis, D, "Paradigms in Information Retrieval Research," *Encyclopedia of Library and Information Science*, Vol.54(1994), pp.275-291.

cognitive abilities such as vocabulary comprehension, logical reasoning, spatial orientation, and perceptual speed, and found that all of them influenced the way people interact with end-user bibliographic information retrieval systems.[2)]

Ⅲ. Cognitive Ability

Cognitive ability, aptitude, and intelligence are interchangeably used to describe individual differences in cognitive performance. The common definition of intelligence includes the ability to learn, to adapt to new situations, and to solve problems. We know very little about the mechanisms that cause individual differences in basic cognitive ability. Mayer refers to intelligence (or cognitive ability) as, "internal cognitive characteristics that are related to individual differences in problem-solving performance" .[3)]

Individuals bring to an instructional environment unique psychological characteristics that influence their learning. These psychological characteristics interact with the process of learning tasks and instructional methods for these tasks. Snow contends that each individual interacts with an instructional method differently, and different methods of instruction facilitate different types of cognitive outcomes. Individual differences in cognitive ability influence all types of learning, including information searching.[4)] There is no agreement on how many different cognitive factors are involved in intelligence. Some psychologists consider only one ability, general intelligence. Other psychologists have proposed as many as 120 factors.[5)]

Numerous measuring instruments have been developed to measure cognitive ability. For instance, 72 tests from the Kit of Factor-Referenced Cognitive Test are designed to measure 23 different mental factors.[6)]

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2) Allen, B. L., "Cognitive differences in end user searching of a CD-ROM index. SIGIR 92: Proceedings of the 15th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval" (1992) pp.298-309.

3) Mayer, R. E, *Thinking, problem solving, cognition* (San Francisco, Freeman 1983) p.301.

4) Snow, R. E. "Aptitude processes. Aptitude, Learning, and Instruction" (1980)

5) Guilford, J. P., "Cognitive styles: what are they," *Educational and Psychological Measurement,* Vol,40(1980), pp.715-735.

Cognitive abilities have been used to predict a number of work outcomes in organizations. For example, John E. Hunter reviewed evidence from hundreds of studies showing that relevant cognitive abilities predict the level of work performance.[7] In the library setting, Teitelbaum-Kronish found that there is a positive relationship between logical reasoning ability and successful online searching.[8] Since the early 90's, Bryce Allen has been considered themost active researcher in the area of information searching behavior. Allen focused on the activation of organizing cognitive structures (schemata) that guide the processes of reading, understanding, and recall, and found an interaction between search topics and the user's knowledge structures.[9] In a later study, Allen found that users with extensive knowledge of a topic used more search expressions than users who knew little about a topic.[10] In a similar study, Allen & Allen examined the logical reasoning ability, verbal comprehension, and perceptual speed differences between librarians and students.[11] The librarians had higher average logical and verbal comprehension abilities than the students, but students had higher average perceptual speed. These findings suggest the need for different approaches to IR design. Allen found that perceptual speed and cognitive abilities such as logical reasoning and verbal comprehension influenced information seeking in a CD-ROM bibliographic database.[12] Based on these results, Allen recommended that the display of linear lists of hits be modified for users who lack perceptual speed, perhaps using a hierarchical display of document lists. His results are related to those of Vicente, Hayes, and Williges whose research reported the importance of spatial ability to users of hierarchical file systems.[13]

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6) Ekstrom, R. B., French, J. W., & Harmon, H., *Manual for Kit of Factor-referenced Cognitive Tests*(Trenton, NJ: Educational Testing Service, 1976).
7) Hunter, J., "Cognitive ability, cognitive aptitudes, job knowledge, and job performance," *Journal of Vocational Behavior*, Vol.29(1986), pp.340-362.
8) Teitelbaum-Kronsh, P., "Relatioships of selected cognitive aptitudes and personality characteristics of the online searcher to the quality of performance in online bibliographic retrieval"(Unpublished doctoral dissertation, New York University, New York, 1985).
9) Allen, B. L., "The effects of academic background on statements of information need," *The Library Quarterly*, Vol.60(1990), pp.120-38.
10) Allen, B. L., "Topic knowledge and online catalog search formulation" *The Library Quarterly,* Vol.61(1991), pp.188-213.
11) Allen, B. L., "Logical reasoning and retrieval performance," *Library & Information Science Research*, Vol.15(1993), pp.93-105.
12) Allen, B. L. *op. cit.*, pp.298-309.
13) Vicente, K. J., Hayes, B. C., & Williges, R. C"Assaying and isolating individual differences in searching a hierarchical file system," *Human Factors*, Vol.29, No.3(1987), p.349.

These results remind information system designers to consider browsers' perceptual and spatial abilities.

1. Spatial Visualization

Spatial visualization requires that the figure be mentally restructured into components for manipulation. Tests of spatial visualization ability are constructed to tap an analytic strategy that some may employ. The ability to visualize is considered a major cognitive factor in intelligence tests or aptitude tests.

Spatial visualization is strongly related to academic performance in mathematics and engineering.[14] Several studies found a positive relationship between spatial visualization ability and success in learning.[15]·[16] Sein and others concentrated on the user's visualization skill as a significant cognitive factor.[17] These researchers found that high spatial visualization ability is a significant predictor of success in learning. Subjects with low spatial visualization could improve this skill with training, which includes the use of analogical conceptual models. Although none of these studies used actual information retrieval (IR) systems, information system designers can include direct manipulation interfaces in their designs to accommodate users' visualization abilities. Searching tasks that require a series of actions or reorganization of previous searches may require extensive spatial visualization ability.

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14) Fletcher, S. "Cognitive abilities and computer programming" ERIC Document Reproduction Service No. ED 259 700.(1984)

15) Anick, P., Brennan, J. et al. "A direct manipulation interface for Boolean information retrieval via natural language query. SIGIR '90: Proceedings of the Association for Computing Machinery Special Interest Group on Information Retrieval 13th International Conference on Research and Development in Information Retrieval" (1990) pp.135-150.

16) Sein, M. et al.."Visualization ability as a predictor of user learning success," *International Journal of Man-Machine Studies*, Vol.39, No.4(1993), pp.599-620.

17) Sein, M., *op. cit.* pp.599-620.

2. Logical Inductive Reasoning

The logical reasoning ability of the user would be another characteristic of successful information retrieval. Teitelbaum-Kronish found a significant relationship between logical reasoning ability and online searching success.[18] People who reasoned logically did better in online searches than did those with poorer logical skills. Similarly, people who did better in integrative process reasoning were more successful than those who could not do this. Greene and others found that the logical reasoning and integrative processes affected a user's ability to use logical operators such as AND, OR, and NOT.[19] Other investigations using different types of information retrieval system have added to the body of findings that indicate the importance of cognitive abilities in information work.[20] [21]

3. Integrative Process Reasoning

Integrative process reasoning is a cognitive factor that is named "integrative processes" in the manual for the Kit of Factor-Referenced Cognitive Tests. Even though this factor has not been used in LIS research, the definition of this factor is essential to the information searching environment. For instance, searchers have to pay attention at each stage during the search process while interacting with the system. Mayer and others examined both general and specific thinking skills.[22] They referred to the integrative processing factor as a specific thinking skill, since this cognitive factor is readily teachablecompared to other cognitive factors that are more resistant to change. As reflected in the conceptual definition of integrative process reasoning, information searching performance seems to require the ability to use several system's features in a single searching task.

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18) Teitelbaum-Kronsh, P., *op. cit.*
19) Greene, S. L. et al., "No IFs, ANDs or ORs: a study of database querying," *International Journal of Man-Machine Studies*, Vol.32(1990), pp.303-326.
20) Allen, B. L., *op. cit*, pp.93-105.
21) Ford, N., wilson, T., foster, A., Ellis, D., & Spink, A." Individual differences in information seeking: an empirical study," *ASIS 2000 Proceedings of the 63rd Annual Meeting of the American Society for Information Science,* Vol.37(2000), pp.14-24.
22) Mayer, R. E, *op. cit*

Ⅳ. Methods

1. Subjects and Test Procedures

Seventy subjects were recruited from the University of Wisconsin-Madison campus during the 2000 Spring and Fall semesters by distributing recruitment letters to undergraduate classes and posting signs in campus libraries. Subjects first took three different standardized cognitive tests (using paper and pencil) that required approximately half an hour to complete. Then participants had 30 minutes to perform online catalog searching in response to seven information search questions.

The searches were logged using Lotus ScreenCam, a software program that captures PC screen. Each search log was saved as a file, and played back the search history and analyzed to identify the decisions the searcher made.

2. Information Searching Performance Measure

Searching performance can be viewed as an activity that involves making decisions at many separate and distinct stages. For the purpose of assessing students' information searching performance, the dependent variables relating to searching performance are classified into two: (1) searching process, and (2) searching outcome.

Searching process is defined conceptually as a searcher's utilization of appropriate system features when needed to conduct an information search. Seven search process variables are selected to measure searching process:

search command selection
combination of search commands
application of Boolean logic
application of truncation
use of limit search function
number of search statements
number of search errors made

Searching outcome is defined conceptually as correctness of the records produced by the search input that is derived from a search question. It is operationalized as the number of correct answers to the seven search question. Correct answers substantially match the researcher's predetermined answers, and anything else is treated as an incorrect response.

3. Cognitive Ability Measures

Conceptually, cognitive ability is defined in this study as, "the content, component processes, and level of cognition to the questions of What?, How much?, and What kind of information is being processed by what operation in what form and how well?" [23)]

Three selected facets of cognitive ability (spatial visualization, logical inductive reasoning, and integrative process reasoning) were measured. All three tests were selected from the Kit of Factor-Referenced Cognitive Tests which were developed by the Educational Testing Service. [24)]

- Conceptually, spatial visualization is defined as "the ability to manipulate or transform the image of spatial patterns into other arrangements"[25)] For this study, spatial visualization was measured by the Paper Folding Test. In this test, figures are drawn to show each step of paper folding. The last folded figure has one punched on a folded portion. Subjects were asked to choose from among five figures the one that shows the correct pattern of hole punches if the paper were no longer folded. The test contains 10 items, and time was limited to three minutes.

- Conceptually, logical inductive reasoning is "the ability to reason from stated premises to their necessary conclusion." For this study, logical inductive reasoning is measured by the Letter Sets Test. Five sets of letters is presented with four letters in each set. Four of the sets were alike in some way. Subjects were asked to find the odd set

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23) Messick, M., "The nature of cognitive styles: problems and promise in educational practice." *Educational Psychologist*, Vol.19, No.2(1984), pp.59-74.
24) Ekstrom, R. B., French, J. W., & Harmon, H., *op. cit*
25) Ekstrom, R. B., French, J. W., & Harmon, H., *op. cit*

from the five sets of letters. There are 15 items with seven minutes allowed to complete the test.

· Conceptually, integrative process reasoning is "the ability to combine several conditions or rules in order to produce a correct response" [26] For this study, integrative process reasoning ismeasured by the Following Direction Test. This test measures a cognitive ability called "Integrative Processes" that is supposedly the ability to process multiple variables simultaneously.[27] Subjects were asked to determine the correct letter in a matrix of letters by following a complex set of directions. Seven minutes were given to complete the 10 items.

Ⅴ. Analysis and Results

Three different statistical methods were applied for the analyses of the study. They were zero order correlation, factor analysis, and multiple regression analysis. First, a zero order correlation table was created to determine the correlation between the independent variable and dependent variable. Second, exploratory factor analysis was used to find underlying structures of the seven search process variables. Third, multiple regression analysis was applied to examine the predictive power of three cognitive variables on three extracted factors, and search outcome.

1. Zero Order Correlations Between Variables

The correlations between three independent variables and eight dependent variables were examined in this section. Zero-order correlation results <Tab. 1> indicated that visualization ability was found to be positively correlated withsearch command selection,

26) Ekstrom, R. B., French, J. W., & Harmon, H., *op. cit*
27) Ekstrom, R. B., French, J. W., & Harmon, H., *op. cit*

combination of command, application of Boolean logic, the number of search statements, and the number of search errors made.

<Tab. 1> also showed that logical reasoning was found to be positively correlated with search command selection, combination of command, application of Boolean logic, application of truncation, use of search limit function, and the number of search errors made. Integrative reasoning was found to be positively correlated with search command selection, application of Boolean logic, and the number of search errors made. Zero-order correlation results <Tab. 1> indicated that only logical reasoning was found to be positively correlated with search outcome.

<Tab. 1> Results of Zero-Order Correlations(Tested at p<.05, One Tailed, n=70)

Criterion Variab / Predictor Variable	Search Proce							Search Outcome
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Success
Visualization ability	.41*	30*	.30*	.15	.03	.23*	25*	.04
Logical reasoning	.46*	.44*	.49*	.22*	.30*	.17	..27*	44*
Integrative reasoning	.29*	15	.24*	.13	.07	.15	.20*	.23*

[Notes: * p<.05, p values are based on one-tailed significance, n=70]

(1) search command selection
(2) combination of commands
(3) application of Boolean logic
(4) application of truncation
(5) use of limit search function
(6) number of search statements
(7) number of search errors made

2. Exploring the Factorsof Information Searching Process

This section describes the procedures used to extract factors out of seven dependent variables by applying factor analysis. Principal componentfactor analysis was run by SPSS to determine the appropriate number of factors, three factors with eigenvalues exceeding or close to 1.0 were identified, accounting for 85% of the total variance. The remaining four factors together account for only the final 15% of the variance. Thus, a three-factor solution was selected for the analysis.

<Tab. 2> is the rotated factor matrix for seven process variables. Tab. 2 shows that the variables: the application of Boolean logic, combination of commands, and command selectionload most heavily on the first factor. This factor is labeled as the **primary search process** because it plays an essential role in selecting the field of record (command selection), in combining fields, if more than one field is identified by the searcher (combination of commands), and in applying Boolean operators to combine selected fields (application of Boolean logic).

The variables: the number of search statements, and the number of search errors made load most heavily with factor 2. This factor is labeled as the **resultant search process** because it is the dimension that is not under direct control of a searcher; it is rather a byproduct of primary and advanced processes and is not an intended process of the search.

The variables: the application of truncation, and use of limit search function load most heavily on factor 3. This factor is labeled as the **advanced search process** because it is a relatively high level of search process, and less commonly used among undergraduate students. The advanced process should be accompanied with the primary process by limiting a specific category. For example, MadCat provides six categories (date, language, type of material, location, publication statues, place of publication) offered by the system, or by truncating the search term.

<Tab. 2> Rotated Factor Matrix with Factor Loadings for Seven Process Variables (Dependent Variables n=70)

Variable	Factor1	Factor2	Factor3
Command selection	.79	.38	.09
Combination of command	**.94**	.19	.10
Application of Boolean logic	**.93**	.21	.16
Application of truncation	.04	.00	**.92**
Use of limit search function	.27	.38	**.64**
Number of search statement	.26	**.89**	.11
Number of search errors made	.27	**.89**	.12

[Note: Three-factor solution was rotated using an orthogonal (varimax) criterion]

[Items in **Bold** selected for factor]

Factor scores were computed for each case, and saved in dataset. These factor scores were used in subsequent analyses to determine the relationships of three cognitive variables and the three factors.

3. Multiple Regression of Three Cognitive Variables on Primary, Advanced, and Resultant Processes

Multiple regression analysis was used to assess what variables can be used to explain three process factors, and to derive the best predictors within the set of independent variables. The method of simultaneous entry of independent variables was used to assess the multiple correlation between a dependent variable and independent variables, and to assess the impact of each independent variable controlling for the others.

In the following section, the results of applying multiple regression to try predicting the primary, the advanced, and the resultant processes are reported.

<Tab. 3> Multiple Regression Results for Predicting Primary, Advanced, and Resultant Processes from Three Cognitive Variables

	(1) Primary Process		(2) Advanced Process		(3) Resultant Process	
Variable	Beta	SE	Beta	SE	Beta	SE
Visualization	.20	.04	-.01	.05	.12	.05
Logical reasoning	.41*	.05	.21	.05	.03	.05
Integrative reasoning	.02	.05	.01	.06	.08	.60

[Note : Column entries arestandardized regression coefficients (beta), and associated standard error (SE)]

(1) Results of the multiple regression, in which visualization ability, logical reasoning, and integrative reasoning were regressed on the **primary process**, are presented in Table 3. The regression analysis produced a significant result, R^2 = .25, $F(3, 66) = 7.5$, $p<.05$. Logical reasoning (beta=.41) were entered in the regression equation as a predictor of primary process. Visualization ability and integrative reasoning were not found to make a significant contribution to the prediction, beyond the contribution made bylogical

reasoning, and were thus not entered.

(2) Results of the multiple regression, in which visualization ability, logical reasoning, and integrative reasoning were regressed on the **advanced process**, are presented in Table 3. The regression analysis did not produce a significant result, F (3, 66) = 1.04, p= .38. Visualization ability, logical reasoning, and integrative reasoning were not found to make asignificant contribution to the prediction.

(3) Results of the multiple regression, in which visualization ability, logical reasoning, and integrative reasoning were regressed on the **resultant process**, are presented in <Tab. 3> The regression analysis did not produce a significant result, F (3, 66) = .70, p= .56. Visualization ability, logical reasoning,and integrative reasoning were not found to make a significant contribution to the prediction.

4. Multiple Regression of Three Cognitive Variables on Search Outcome

This section reports a regression model to predict search outcome.

Results of the multiple regression, in which visualization ability, logical reasoning, and integrative reasoning were regressed on search outcome, are presented in Table 4. The regression analysis produced a significant result, R2 = .22, F (3, 66) = 6.07, p<.05. Logical reasoning was entered in the regression equation as a predictor of search outcome. Visualization ability and integrative reasoning were not found to make a significant contribution to the prediction, beyond the contribution made by logical reasoning, and were thus not entered.

<Tab. 4> Multiple Regression Results for Predicting Search Outcome from Three Cognitive Variables

Variable	Beta	SE
Visualization	-.10	.05
Logical reasoning	.42*	.05
Integrative reasoning	.13	.06

Note. Column entries are standardized regression coefficients (beta), and associated standard error (SE).

Ⅵ. Discussions: Cognitive Abilities and Search Performance

Three cognitive abilities examined in this study were visualization ability, logical reasoning, and integrative reasoning. Visualization ability correlated positively with the process variables of search command, combination of command, application of Boolean logic, the number of search statement, and the number of search errors made, but no correlations were found between visualization ability and the application of truncation, orthe use of search limit function. Further, it was found that whilevisualization was correlated positively with process variables, but it was not found to correlate positively with search outcome. Visualization abilityrequires that the figure be mentally restructured into components for manipulation. The findings indicated that individuals who had more abilities to manipulate or transform the image of spatial patterns into other arrangement, performed better during the search process. However, visualization ability was not associated with outcome of the search.

Logical reasoning was found to be correlated with six process variables but not with number of search statements. The logical reasoning ability of the user is thought to be another characteristic of successful information searcher. In an empirical study, Teitelbaum-Kronish found that library school students who had better logical reasoning did better online searches.[28] He did not measure search process directly, but his results indicated that logical reasoning was found to be a predictor to searching performance. The current study showed that higher level of logical reasoning made a greater difference in the primary process, but did not influence the advanced and resultant processes. The finding also indicated that logical reasoning ability was strongly correlated with search outcome. This result is consistent with Teitelbaum-Kronish and Allen's findings.[29] Teitelbaum-Kronish found a significant relationship between cognitive ability and online searching success.[30] In their studies, people who reasoned logically did better in online searches than did those with poorerlogical skills. In this study, logical reasoning ability was found to be a strong predictor of both searching process and searching outcome.

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28) Teitelbaum-Kronsh, P., *op. cit.*
29) Teitelbaum-Kronsh, P., *op. cit.*
30) Teitelbaum-Kronsh, P., *op. cit.*

The results of this study showed that integrative reasoning was the least important cognitive variable of the three selected for study. Even though integrative reasoning was found to be positively correlated with three process variables, multiple regression analysis indicated that it was not found to make any predictions to the primary, the advance, or resultant processes in the equation models. Another finding indicated that search outcomecould not be impacted by integrative reasoning. Thus, the findings of this study demonstrated that the ability to follow a complex set of directions or to handle a set of complex rules did not account for the search process and search outcome.

In summary, this research investigated the relationships of cognitive characteristics with search process, and search outcome. Results of the data analysis showed that individual differences in logical reasoning were associated with information searching processes and outcomes.

Ⅶ. Conclusions

The purpose of the study was to examine the relationship between three cognitive abilities and measures of information searching performance. Cognitive ability led to the user's searching process that, directly or indirectly, determined information searching performance. This study has contributed to the understanding of the relationships between cognitive characteristics and information search process and search outcome. The results of this study emphasize the importance of considering cognitive variables as important contributors to information search process and outcome.

The results suggest information system designers that a future information system should have a flexibility that can respond more accurately to cognitively diverse user population.

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