8-25-1995

An Experimental Study of the Relationship BetweenSpatial Ability and the Learning of a Graphical User Interface

Bob Leitheiser
University of Wisconsin-Whitewater, leitheir@uwwvax.uww.edu

David Munro
University of Wisconsin-Whitewater, munrod@uwwvax.uww.edu

An Experimental Study of the Relationship Between Spatial Ability and the Learning of a Graphical User Interface

Bob Leitheiser and David Munro; Management Computer Systems
University of Wisconsin-Whitewater; Whitewater, WI 53190-1790
(414) 472-1467; leitheir@uwwvax.uww.edu; munrod@uwwvax.uww.edu

"The Graphical User Interface (GUI) is one of the most revolutionary changes to occur in the evolution of modern computing systems. ... This revolution has increased the accessibility and usability of computer systems to the general public ..." (Mandelkern, 1993, p. 37). In the excitement over Graphical User Interfaces, developers often overlook the fact that they are making assumptions about how users best process information. A key assumption in the GUI is that users are effective processors of spatial information. In fact, there are individual differences in how well people process information spatially. This paper describes an experiment that measures these differences and looks for their effects on users' abilities to learn command line and GUI interfaces for simple file management tasks.

Prior Research

Psychologists have long distinguished between spatial and other abilities. McGee (1979) traces studies that produce spatial ability factors back to 1925. Based on his review, McGee concludes that there are at least two spatial factors: (1) visualization -- "... the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object." (p. 893); and (2) spatial orientation -- "... the comprehension of the arrangement of elements within a visual stimulus pattern and the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented" (p. 893). Another spatial factor that has been identified and investigated is Visual Memory (Ekstrom, French & Harman, 1976) which is the ability to remember spatial information. Since GUI's rely on the spatial positioning of objects or symbols to communicate with users, their effectiveness may depend on the ability of those users to comprehend, manipulate, and remember spatial information. Furthermore, there is evidence that subjects vary their problem solving strategies depending on their spatial abilities (French, 1965; MacLeod, Hunt, and Mathews, 1978; Sternberg & Weil, 1980; and Presson, 1982). If systems that support individual problem solving styles are desirable, then highly spatial interfaces may not be suited to all users.

Only very limited research has been done on the influence of spatial ability on computer use. Egan and Gomez (1985) conducted a series of four experiments to identify and accommodate individual differences that affect the learning of computer text editing. Reading ability was found to be related to performance on the reading components of the experiment, but spatial memory and age were found to have the greatest influences on learning how to interact with the computer. While age differences seemed to diminish when a full screen editor was used instead of a line editor, the impact of spatial memory remained. Interestingly, in the final experiment a measure for spatial visualization was also included but did not explain performance as well as spatial memory. The authors propose a model for text editing that suggests a role for spatial memory when acquiring the editing task and generating the editing action.

Gagnon (1985) studied the relationship between spatial skills and video games. She found that scores on a two dimensional spatial test were related to scores on a two dimensional video game while spatial visualization scores (3 dimensional test) were related to scores for a three dimensional game. Interestingly, eye-hand coordination was not found to be related to video scores or spatial test scores. Male subjects tested higher on spatial tests than female subjects but the latter were able to significantly improve their spatial test scores after video game practice. As in the Egan and Gomez study, age was found to be negatively correlated with performance.

Vincente, Hayes, and Williges (1987) performed a database interaction experiment. They found that spatial visualization scores were the best predictors of performance. Low spatial ability subjects took on the average twice as long as high spatial subjects. Computer experience was not found to contribute to performance prediction. These studies suggest that spatial ability should be considered in the design of interfaces and training for information systems.

Experiment

A within subjects experiment was designed to investigate the effects of spatial abilities on the effectiveness of a Graphical User Interface. GUI effectiveness was evaluated by comparing how long it took subjects to complete a set of simple operating system tasks on a GUI interface with how long it took them to do the same tasks on a conventional command line interface. The two interfaces were Microsoft DOS (conventional command line) and Apple Macintosh (GUI). The dependent variable was the ratio of GUI task times to command line task times. The goal of the study is to investigate whether individual differences affect the effectiveness of the user interface.

Two hypotheses were posited. Because of the spatial nature of GUI's it was hypothesized that users with high spatial ability would benefit more from their use than those of low spatial ability (H1). By the same logic, users with high verbal ability should perform better on command line interfaces because these interfaces rely on the linear nature of normal text (H2).

The experimental tasks were the same for both interfaces and consisted of: (1) obtaining system times, (2) listing files, (3) looking up a file update time, (4) opening a subdirectory, (5) moving a file, (6) copying a file, (7) deleting a file, (8) changing a file name, and (9) removing a subdirectory. Subjects performed the complete set of tasks for each interface during separate sessions. Approximately half of the subjects learned the GUI interface first while the other half did the command line interface.

The subjects used in the experiment were drawn from four sections of an introductory computer class and randomly assigned to one of the order treatment groups (i.e., GUI first or command line first). Standard measures were taken of spatial visualization, spatial memory, and verbal ability (Ekstrom, French & Harman, 1976). Measures were also taken of prior student experience with DOS and Macintosh systems. For this analysis, subjects who had significant prior experience were dropped so that this experience would not unduly affect the results. Out of 132 participants, 68 were used in the analysis. Based on their scores, subjects were classified as being high or low in spatial visualization, spatial memory and verbal ability.

Each experimental session consisted of an instructor describing and demonstrating each task for subjects. A script was prepared for GUI and command line sessions that varied only in the text needed to describe the interface details. The length of the two scripts was the same. Following the presentation students were left on their own to complete the tasks that were listed on a printed handout. The instructor was allowed to give short, clarifying answers to specific subject questions. The first and last task had the subjects record the system time which was used as the means for capturing learning time.

An analysis of variance was performed using the ratio of GUI time to command line time as the dependent variable. The factors examined were (1) order of presentation of interface, (2) spatial visualization, (3) spatial memory, and (4) verbal ability. Not surprisingly, an order affect was found ($F=6.93$; $p=.011$). Since the same tasks were performed for both interface sessions, subjects were able to transfer task knowledge from the first to the second session. There was also a significant effect for spatial visualization ($F=5.40$; $p=.024$). When using the GUI, subjects with high spatial visualization scores required only 69% of the time to do the tasks as when they used the command line interface. For subjects with low spatial visualization scores, this ratio was 90%. No effects were found for spatial memory or verbal ability.

Expanding on these findings, ANOVAs were performed using GUI and command line times as dependent variables. The mean of the high spatial visualization group GUI times (819 seconds) was significantly less than the low spatial times (1040 seconds). No differences were found in the command line times.

Conclusion

Our results indicate that Graphical User Interfaces are more effective for users with high spatial ability than they are for users of low spatial ability (H1). Even low spatial ability users, however, performed better with the GUI than they did with the command language interface. Specifically, they required 90% of the time used for the command language interface. We found no evidence that a different group of users (i.e., high verbal ability subjects) would perform at a higher level with a non-GUI interface than they would with a GUI (H2). The emphasis on GUI designs, therefore, appears to be justified, especially for high spatial users. Further research might explore how low spatial ability subjects could be accommodated with other interface features.

References

Egan, Dennis E., and Gomez, Louis M. (1985). Assaying, Isolating, and Accommodating Individual Differences in Learning a Complex Skill. In Dillon, R. F., ed., Individual Differences in Cognition, Vol. 2, New York, NY: Academic Press, pp. 173-217.

Ecstrom, R. B., French, J. W., and Harmon, H. H. (1976). Manual for Kit of Factor-Referenced Cognitive Tests. Princeton, NJ: Educational Testing Service.

French, John W. (1965). The Relationship of Problem-Solving Styles to the Factor Composition of Tests. Educational and Psychological Measurement, 25, 1, 9-28.

Gagnon, Diana (1985). Videogames and Spatial Skills: An Exploratory Study. ECT Journal, 33, 4, 263-275.

French, John W. (1965). The Relationship of Problem-Solving Styles to the Factor Composition of Tests. Educational and Psychological Measurement, 25, 1, 9-28.

MacLeod, Colin M., Hunt, Earl B., and Mathews Nancy N. (1978). Individual Differences in the Verification of Sentance-Picture Relationships. Journal of Verbal Learning and Verbal Behavior, 17, 493-507.

Mandelkern, Dave (1993). GUIs: The Next Generation. Communications of the ACM, 36, 4, 37-39.

McGee, Mark G. (1979). Human Spatial Abilities: Psychometric Studies and Environmental, Genetic, Hormonal, and Neurological Influences. Psychological Bulletin, 86, 5, 889-918.

Sternberg, Robert J., and Weil, Evelyn M. (1980). An Aptitude x Strategy Interaction in Linear Syllogistic Reasoning. Journal of Educational Psychology, 72, 2, 226-239.

Vincente, Kim J., Hayes, Brian C., and Williges, Robert C. (1987). Assaying and isolating individual differences in searching a hierarchical file system. Human Factors, 29, 3, 349-359.