USER INTERACTIONS WITH ALTERNATIVE MAP DISPLAYS IN A GIS ENVIRNOMENT

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Abstract

This paper reports a study which is part of a research programme on user interactions with map displays generated by a geographical information system (GIS). The study examines user differences in the context of three alternative map displays, where the screen display affords different interactive possibilities in terms of overlaying variables on a single map or of viewing more than one map at a time. Fifty-nine novices (psychology undergraduates) and forty experts (geography students with hands-on training in GIS) explored two problem scenarios (the Peat Scenario on machine peat cutting, and the Health Scenario on health/poverty statistics) for a maximum of 15 minutes each. Measures of the interaction were on-screen performance, summary conclusions, and self-reported strategies. An important finding was that the experts' general conclusions from the databases were superior to the novices' conclusions in only two of the three display conditions for both problem scenarios. Results are discussed in terms of the transparency of the map displays for different user groups.

1 Introduction

This paper reports a study which is part of a research programme designed to evaluate how users interact with map displays in a GIS environment [1]. The programme provides a cognitive analysis of the interaction and it focuses on the problem-solving and reasoning strategies of users with different levels of GIS expertise. The current study manipulates the map display in terms of "multiple views" - where the the screen display affords different interactive possibilities in terms of overlaying variables on a single map or of viewing more than one map at a time.

Map displays within a GIS environment can best be characterised as visualisation tools in the sense that they permit users not only to produce computerised maps but to interact with databases to learn facts about spatial data, to hypothesise, analyse and synthesise spatial relationships. Many writers [2,3] have commented on the opportunities which computerisation affords to transform visual thinking and communication; to move away from the single optimal map to multiple views, 3-D images, time and movement animation, multi-media and so on. However, the development of such tools needs to keep user goals, characteristics and requirements firmly in view. GIS map displays (and more generally, visualisation tools) can only work if they can create, match, extend or substitute the power of visual cognition.

Within cartographic and GIS research, MacEachren [4] has articulated a new perspective on the role of visualisation in which he defines visualisation and map use in terms of the aims and goals of the user. He describes map use in terms of a threedimensional space. The first dimension draws a distinction between public and private uses of maps - between maps which a person generates to support his/her own thinking compared to maps which are used to communicate with a wider audience. The second dimension contrasts maps which are used to reveal previously unknown information with maps which present well-known information which a user might want to access. And the third dimension compares situations in which a user has an opportunity to interact with the map and to change it in substantial ways with those in which no user interaction is possible. Although these distinctions cannot always be so sharply drawn, and not all map uses may be captured in the space, neveretheless, it does provide a useful conceptual tool for analysing the cognitive demands on map users.

The map uses in the GIS environment that we have been studying can best be characterised by high interaction to reveal previously unknown information for the purposes of private thinking and understanding. Our research programme has adopted a distinctively cognitive perspective on the user - a model of "map user as thinker". When the map user is construed as a thinker who explores a spatial database with the aid of a visualisation tool, then considerable variability can be expected between users who are doing the same task. The influence of prior knowledge and expertise, as a source of individual differences between users, is one of the primary variables of interest in our research programme. Previous studies which have compared the effects of expertise on complex visual information processing (albeit static single view displays, e.g. chess boards, circuit diagrams, x-rays, hardcopy maps) have shown that the pattern recognition which is typical of the expert has a major impact on how a visual display is interpreted and searched, and ultimately, on the problem solutions generated from the displays (see McGuinness for a brief review [5]). These differences have usually been interpreted in terms of the schematic nature of the experts' knowledge structures and knowledge organisation. Experts, it is argued, have both general and domain specific problem schemas which are relevant to the display; these schemas influence what is noticed in the display, what is remembered from the display, what is inferred, what is hypothesised and what is the next step.

Expert differences in knowledge structures and their effects on interactions with map displays in a GIS environment were examined in the first study in our research programme which used a thinking aloud or verbal protocol methodology [6]. Eighteen users (9 novices, 9 experts) who differed in terms of their geographical knowledge and GIS experience were studied as they explored two spatial databases. A distinctive expert style of interaction with the databases was identified. For example, the experts explained that they made systematic searches through the database which was confirmed by counting the number and type of variables which they plotted on the maps. They reported testing hypotheses and checking interpretations (evidenced by plotting the same combinations of variables more than once). In contrast, the novices often randomly searched, missed out variables, and engaged only in local and superficial hypothesis testing. Where it was possible to overlay many variables, the experts were conservative about overlaying; they plotted and replotted variables in sequential displays rather than cluttering a single map with too many variables. Through this problem solving and hypothesis testing strategy, the experts were judged to have reached a more adequate assessment of the data novices.

The purpose of the current study was to explore further features of this expert interactional style with a larger number of users and in the context of alternative map displays. In the previous study, users had been permitted to draw only a single map on the screen at any one time but they were allowed multiple overlays on the map. The idea of "multiple views" of the data emerged as important to the users, and the degree to which they chose to simultaneously view variables or to sequentially plot them on different maps discriminated the experts from the novices. For these reasons, the study to be reported examined three map display conditions where the screen displays afforded different interactive possibilities in terms of overlaying variables on a single map or of viewing more than one map at a time.

2 Method

2.1 Subjects

Ninety-nine users (43 men and 56 women) were studied. Forty undergraduate geographers in their second and third years of study, who had particpated in a hands-on course in GIS constituted the 'expert' group. The other fifty-nine users - the novices - were psychology undergraduates with no knowledge of GIS. All users were computer literate. Additional user information was collected on the level of geography education (course participation, e.g., O-level, A-level, 1st year undergraduate, degree level), a self-rated questionnaire (ratings from 1-5) on frequency of map use, degree of map enjoyment and map competence. A psychometric test of spatial ability, the Hidden Figures Test, was completed by all users to measure individual differences in the ability to find simple forms in more complex figures - an ability which might be related to a GIS data exploration task.

2.2 Tasks

The two problem scenarios used in the previous verbal protocol study [6] formed the basis for the current study. The tasks were run through ARC/INFO (the display module, ARCPLOT) on an IBM PC compatible: using the ARC/INFO macro facility we succeeded in making the map plotting readily accessible, even for novice users.

The Peat Scenario: This task drew on a database to do with machine peat cutting in the Sperrin Mountains in Co. Tyrone in Northern Ireland. Eight variables (from nine in the original study) were available for plotting - incidence of machine cutting, contours, roads, rivers, rainline,rainstations, areas of natural beauty/scientific interest, density of wading birds. The purpose for which the data was originally collected was to examine how environmental and social variables were related to the incidence of machine cutting, with particular reference to any conflicts which might exist between economic and conservation pressures. This general storyline formed the background to the scenario and the experimental task mimicked as closely as possible what a "real" GIS user might do when s/he first viewed the data - examine the distribution of variables, explore the relationships and begin to test for patterns. Subjects were invited to pretend that they had to prepare a brief for a talk to the local conservation society on the impact of machine peat cutting in the area. They were presented with a blank screen on which to draw their series of maps, and the list of variables which could be plotted. The map displays which the system permitted depended on what condition the user was assigned to (see below for a description of the alternative map displays).

The Health Scenario: The second task drew on a database which consisted of health and deprivation variables which had been collected at the level of District Council (N=26) in Northern Ireland. Seven variables could be plotted: rate of premature mortality, % permanently sick and disabled, % low birth-weight (these were the health indices); % unemployed, % households without a car, % rented accommodation, and % overcrowding (these were the deprivation indices). To simplify the data, each variable was dichotomised into High/Low and a large or small triangle signified the status of variables for each District Council. The purpose for which the data was originally collected was to examine the spatial distribution of health and deprivation indices, to see the relationship between the variables, and to look for spatial patterning. This general storyline formed the background to the problem. Subjects were asked to pretend that they were acting as research assistants for their local Member of the European Parliament; they had to prepare a brief about the spatial relationships between health and deprivation indices in Northern Ireland. On the screen they were presented with a map of the District Council regions of Northern Ireland and a list of variables to be plotted. As with the Peat Scenario, the map displays which the system permitted depended on the what condition the user was assigned to (see below for a description of the alternative map displays).

2.3 Alternative Map Displays

For both scenarios, three alternative map displays were designed.

Single Variable Map Display . Users were presented with a blank screen and a menu. They could plot and view only one variable on the map. The condition did not permit users to overlay variables on a single map. It deliberately minimised the capability of GIS map displays and resembled the experience of leafing through the pages of a simple electronic atlas; however, users could choose what variable to plot and the sequence in which they viewed the maps.

Multiple Variable Map Display. Users viewed a single map on the screen but they could plot up to 7 variables on a map for the Peat Scenario and two for the Health Scenario. They had to choose what combinations they wished to view together and the sequence in which they viewed the maps. The condition was a replication of the map display which was studied in the original thinking aloud study [6].

Multiple Variable/Multiple Map Display. This condition attempted to give the user simultaneous, multiple views of the data by providing them with the opportunity to plot variables on three maps on the same screen. Users could plot up to 8 variables on each map (24 variables per screen) for the Peat Scenario, and up to 2 variables per map (6 variables per screen) for the Health Scenario. The choices available - about what variables to plot, what combinations to view and on what maps, are considerably increased compared to the other display conditions.

Thirty-three users participated in each condition, Single Variable Condition (20 novices, 13 experts),Multiple Variable Condition (20 novices, 13 experts), Multiple

Variable/Multiple Map Condition (19 novices, 14 experts). For the two scenarios, how the subjects proceeded, what variables they plotted, the reasons they gave for their choices, and the conclusions they reached, constituted "the interaction" with the map display which is the focus for this study.

2.4 Procedure

Users were tested individually and completed the two interactive problem scenarios in a single 90 minute testing session; expert and novice users were randomly assigned to one of the three map conditions. The order of presentation of the problem scenarios was counterbalanced; half the subjects completed the Peat Scenario first while the other half completed the Health Scenario first.

Subjects were given written instructions about the nature of the task requirements and were encouraged to read them and to ask for clarification before they started. They were also given practice on how to use the mouse to select variables. During the task they were allowed to keep notes; at the end of each scenario they had to answer a set of open-ended questions and to explain and justify the conclusions they had reached. The order of completing the tasks for subjects was: doing Problem Scenario 1 (Peat or Health depending on the condition) - 15 minutes; writing summary notes about the first scenario (no time limit); answering questions about the search strategies which they used to complete the first scenario; completing the Hidden Figures Test (10 minutes); doing Problem Scenario 2 (15 minutes); writing summary notes about the second scenario (no time limit); answering questions about the search strategies which they used to complete the second scenario; answering questions about the two scenarios in general; and finally, completing the self-assessment map questionnaire.

2.5 Measures

Users' interactions with the map displays had to be fully captured and three levels of performance were identified to constitute the interaction.

Summary conclusions: Essentially these conclusions revealed how well the subjects had performed the tasks. There were no absolute correct answers because of the open-ended nature of the tasks, so dimensions to assess the quality, goodness or adequacy of the answers were designed: The dimensions used were (1) fulfilment of task requirements, (2) reference to spatial distribution, (3) level of detail, (4) level of interpretation, (5) level of planned structure. Each of these dimensions could earn a score of 2 (very good), 1 (some evidence of) or 0 (very poor); the maximum score available was 10. When a sample of the summary notes was rated according to these dimensions (by two independent raters), they successfully distributed the notes along a dimension - some of the "conclusions" were judged as very good while others were judged as much poorer (when the notes were scored, the raters were blind to their status as expert or novice).

On-screen performance: captured the physical interaction with the map displays. It included the time spent on each scenario in minutes; number of trials per scenario (a new trial began when previously plotted variables were zeroed); absolute number of variables explored per scenario (maximum of 7); number of overlays on a single map (where more than one was permitted); number of repetitions (variables replotted over a series of trials).

Self-reported strategy questionnaire: After completing the exploration of each scenario, users answered three open-ended questions about the approach they adopted to accomplish the task. Then they were given a list of strategies (identified from the previous thinking aloud study) and asked to choose one which best described the way they retrieved or searched for the information. The strategies were: Random Search (a trial and error type of approach), Systematic Search (a more systematic or planful search of the variables), Focussed/Selective Search (tendency to focus on one variable for the majority of the time allocated), Combination of above, None of the above. Finally, users were asked to explain why they had made their choice.

3. Results

Before reporting how the subjects performed on the tasks, additional information about the characteristics of the groups will be described.

3.1 Characteristics of the user groups

The users were recruited as expert or novice depending on the amount of previous GIS experience and training. The experts' GIS experience was not extensive; 39 of the 40 experts were studying geography as their major undergraduate subject in the second and third year of study, all 39 had completed a hands-on course in GIS, one expert had considerably more GIS experience. In contrast, 48 (out of 59) novices had finished their formal geography education during secondary schooling (after O-levels, at 15 years) and only 5 novices had studied lst year geography at university.

In order to check the comparability of the user groups across the map display conditions, four three-way analyses of variance (expert group x sex x alternative map display) examined any differences between the subgroups in terms of self-rated frequency of map use , frequency of using different types of maps, map competence and map enjoyment. In only one of the analyses did statistical differences between the three map display conditions emerge; users in the Multiple Variable condition rated themselves as marginally less map competent than did users in the other two display conditions, (mean=3.2 compared to mean=3.8 in the other two conditions), $F(1,87)=4.2$, $p<.05$. Sex differences emerged in two analyses, where females rated themselves as less frequent users of maps than males in one display condiiton, $F(2,87)=7.4$, $p<.01$, and as less map competent than males overall, $F(1,87)=8.5$, $p<.01$ (mean for females =3.3, mean for males=3.9). But the biggest statistical effects were associated with differences between expert and novice groups: experts rated themselves as more frequent users of maps, $F(1,87)=35.01$, $p<.0001$; as frequent users of different types of maps, $F(1,87)=52.6$, $p<.0001$; as more map competent, $F(1,87)=10.2$, $p<.01$; and as enjoying maps more than novices, $F(1,87)=18.01$, $p<.0001$. In contrast, no statistical differences emerged between the knowledge groups on the Hidden Figures Test of spatial ability - both groups got an average of 11 items correct from a possible 16, $F(1,87)=.035$, n.s. Sex was the variable which produced the statistical difference on the Hidden Figures Test, $F(1,87)=13.32$, $p<.001$, mean=12.8 for males, mean=9.7 for females. Correlation coefficients between the psychometric test of spatial ability and the self-rated map variables were low.

3.2 Expertise and Alternative Map Displays

Time: After exploring the databases for a maximum of 15 minutes, users were given unlimited time to answer the scenario-related questions and to prepare their briefs in the form of summary conclusions. On average, they spent 11-12 minutes per scenario drawing up the conclusions and justifying their reasoning. For the Peat Scenario there was a marginally significant difference between the user groups, $F(1,87)=3.13$, $p<.08$; the experts (mean=12.8 minutes) took somewhat longer to do the task than the novices (mean=11.2 minutes). There were no significant main effects in terms of map display conditions, $F(2,87)=.534$, n.s. or sex, $F(1,87)=.056$, n.s, nor were there any interactions. The time spent answering the Health Scenario questions showed a different pattern. Overall, significantly more time was spent answering the questions after exploring the Single Variable condition (mean=13.9 minutes) than the other two conditions, Multiple Variable (mean=11.6 minutes) and Multiple Variable/Multiple Map (mean=10.8), $F(2,87)=3.67$, $p<.05$. Also, the males (mean=13 minutes) spent more time on the task than the females (mean=11 minutes), $F(1,87)=3.84$, $p<.053$. There were no other significant interactions between the variables.

Rated Quality of Summary Conclusions: Whatever the differences in the amount of time spent on the tasks by the different user groups, it did not appear to affect the quality of the conclusions they reached. The most important finding was that the experts' conclusions were rated as better than the novices in only two of the three map display conditions. For the Peat Scenario, there was a significant main effect of expertise, $F(1,87)=26.7$, $p<.0001$; the more experienced geographers earned a mean of 8 points (from a possible 10) for their answers compared to 6 points for the novices. But this effect was modified by an interaction between expertise and display condition, $F(2,87)=2.4$, $p=.095$. Figure 1 shows the shape of the interaction. The geographers' advantage is substantial only in the Multiple Variable(expert mean=8.5 vs novice mean=5.7) and the Multiple Variable/Multiple Map (expert mean=7.6 vs novice mean=5.4) conditions; the effect is minimal in the Single Variable condition (expert mean=7.7 vs novice mean=6.9). Simple main effects analyses confirmed that the effect is statistically true despite the marginal statistical significance of the interaction in the analysis of variance. There were no statistical effects for sex.

This overall pattern was repeated in the rated quality of the summary conclusions for the Health Scenario. Analysis of variance showed a statistical main effect for expertise,$F(1, 87)=16.13$, $p<.001$; the experts gained a better understanding of the database (mean=7.3 points) than the novices (mean=5.6 points). The statistical main effect for condition was modified by an interaction between user group and map display, $F(2,87)=2.43$, $p<.093$, which showed that the experts did better only in the Multiple Variable (expert mean=7.8 vs novice mean=4.9 points) and the Multiple Variable/Multiple Map conditions (expert mean=6.5 vs novice mean=4.9 points); there was very little difference between the user groups in the Single Variable condition (expert mean=7.1 vs novice mean=7.7). There were no statistical (or marginally statistical) effects of sex. Figure 2 shows the shape of the interaction between knowledge groups and map displays.

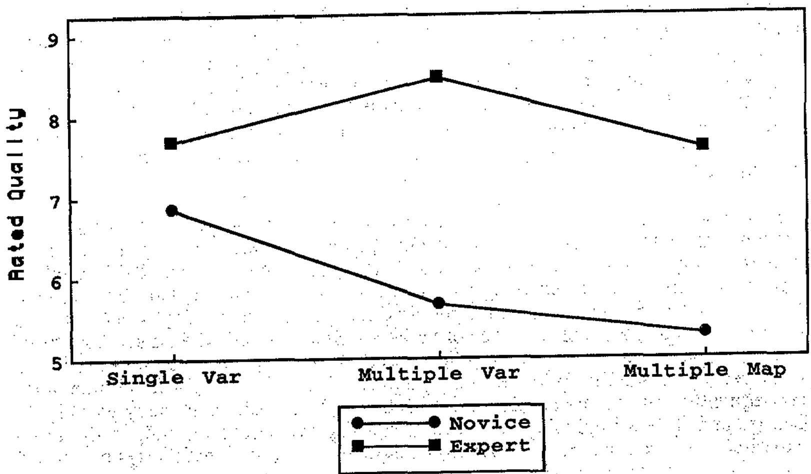

Figure 1. The Peat Scenario: Rated Quality of Summary Conclusions for Novices and Experts in the Three Map Display Conditions.

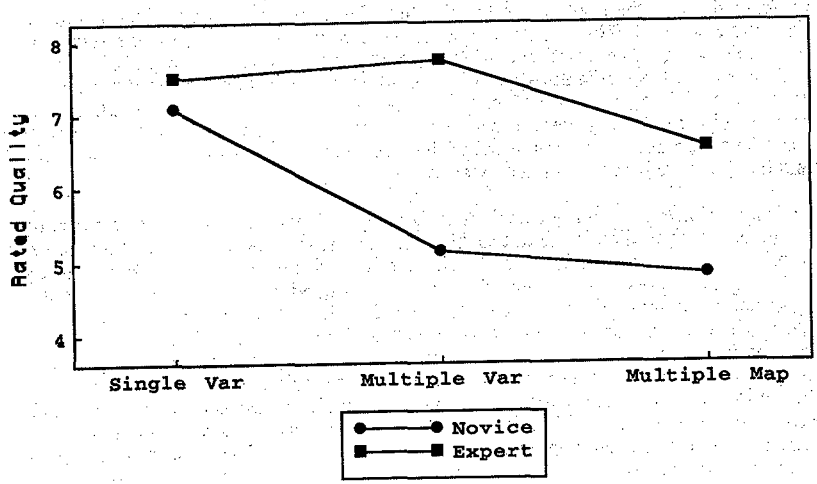

Figure 2. The Health Scenario: Rated Quality of Summary Conclusions for Novices and Experts in the Three Map Display Conditions.

This finding - that experts gain an advantage with two map displays but not with the third- is important because it shows that knowledge or expertise alone is not producing the quality conclusions, but rather how the map display affords or scaffolds the exploration and hypothesis testing with the database for the different user groups. How this exploration proceeded can be more clearly understood when comparisons are made between the user goups in terms of on-screen performance and self-reported search strategies, separately, for each type of map display. These are now summarised:

Interacting with Single Variable Map Displays : With this type of map display users were permitted to view only one variable on the map at a time. Both groups of users produced very similar interactive profiles. They plotted, on average, 18-19 variables within the time allowed, repeating the same variables again and again. For both the Peat and Health Scenarios, all users reported a high frequency of systematic search through the database; the sequence of variables plotted reflected their self-reports of systematic search and were very similar for both the experienced geographers and the novices. The single variable map display afforded very little choice and, consequently, individual variation in interactive style and search strategy was highly constrained. Users invariably found the map display frustrating and, in the post-experimental questionnaire, both groups consistently suggested that the system should allow for putting more than one variable on the map at a time, and/or seeing more than one map simultaneously. Nevertheless, as the data shows in Figures 1 and 2, both experts and novices reached good quality conclusions in their summaries; the experts were as good as they were with the other display conditions, while the novices performed better than with the other displays. Users were allowed to keep notes as they interacted with the database and, when these were examined, it became very clear what methods had been used to complete the task. Essentially users went "off-screen" and developed their own idiosyncratic, but not interactive, methods of exploring the spatial data. They drew rough sketch maps, made tables and restated the spatial relationships by writing them down. These strategies yielded comparable outcomes for both expert and novices in terms of the assessments they made of the information and the understandings which they reached.

Interacting with Multiple Variable Map Displays: This map display was virtually identical to that studied in the initial thinking aloud study where features of the expert interactional style were first noted. The interactive styles which emerged were broadly similar to those previously observed. Experts continued to interact with the map in a systematic way by plotting and replotting variables in sequential displays rather than cluttering a single map with too many variables. The differences in the self-reported strategies of experts and novices were not clear cut; both groups reported a preponderance of systematic or focussed search, either alone or in combination. (The limitations of asking users for a global and retrospective assessment of their search strategies became obvious in this condition - users tended to describe themselves as having a more consistent approach than was evident in their on-screen performance or than was evident in the more fine-grained analysis available in the verbal protocols.) In the long run, the quality of the novices' summary reports were rated lower than the expert users, and they were not as good as the comparable group of novices who were interacting with the Single Variable Map display. It appears that, when mapping opportunities are less constrained, and more choices are available, the low knowledge novice group had more difficulty gaining a full understanding of the relationships in the database.

Interacting with the Multiple Variable/Multiple Map Display: In the display the users were allowed to plot up to three maps per screen. In the Peat Scenario, a user could plot up to 8 variables on a map thus allowing 24 variables to be viewed per screen; in the Health Scenario, up to 6 variables could be viewed per screen - 2 per map. Experts tended to generate more multiple views of the data than novices, in terms of the number of times they replotted the three maps on a screen. Experts did not always take the opportunity to plot variables on the three maps; they did more sequenced plotting while the novices tried to keep "most variables in view". Experts also engaged in more strategic comparison between maps on a single screen display as evidenced by the sequence in which variables were plotted across maps. Novices plotted in a predictable and linear pattern, whereas experts' plotting was more varied and produced complex patterns. Experts appeared to exploit the possibilities of multiple views afforded by the screen displays more so than the novices while, at the same time, they were not overwhelmed by them. For the novices, extending the interactive possibilities with the database did not yield additional understanding in terms of the quality of the conclusions reached; it had the opposite effect.

4 Conclusions

The main finding from this study with alternative map displays is that, for both scenarios, the expert users made more adequate assessments of the databases and reached better quality conclusions in only two of the three map display conditions.

This finding is important because it shows that prior knowledge alone cannot account for the experts'superior performance but rather how the map displays"scaffold" the interaction with the database for the different user groups. When the choices about what and how to map are highly constrained, and the level of interaction is low, then novices match the experts' performance. As soon as the interactive possibilities increase, then an adequate exploration of the data becomes more and more dependent on the expert knowledge and problem solving schemas. The operation of these knowledge schemas are evident in the so-called expert interactional style with the database - hypothesis testing, fine-tuning the questions to be asked of the database, minimising the clutter on the screen display, checking and verifying the knowledge already acquired.

In terms of education and training, many GIS tutorial packages are built around problem scenarios which are not dissimilr to the experimental materials used in our studies. What they lack are opportunities for self-testing and/or for builing flexible map display alternatives. This results of this study point to the important of developing tutorial packages with these features.

5 Acknowledgements

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