TWO-VARIABLE CHOROPLETH MAPS: AN INVESTIGATION OF FOUR ALTERNATE DESIGNS

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TWO-VARIABLE CHOROPLETH MAPS: AN INVESTIGATION OF FOUR ALTERNATE DESIGNS

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ABSTRACT

The two-variable choropleth mapping technique is a statistical mapping method that researchers have only seriously considered since the mid-1970's. The aim of this method is to enable the percipient to distinguish three spatial distributions on a map, i.e. two single geographical distributions and the interrelationship between them. Most of the earliest research questioned the viability of the bivariate choropleth map and found it to be acceptable. Much of the subsequent research was conducted to evaluate its graphic design flexibility to the cartographer and readability to the map user given the intended purpose of the design. This study continues that research trend. Test maps were designed by combining four graphic variables that resulted in the following combinations: value with black pattern, value with white pattern, hue with black pattern, and hue with white pattern. A total of four previously untested experimental maps with a 4x4 matrix legend were created and used in conjunction with a task-specific questionnaire to determine the feasibility of the designs. The utility and validity of these designs were analyzed based on the degree to which subjects could interpret correctly the information displayed on each map. One hundred and twenty university students participated in the study. In the experiment black and white patterns were compared in their effectiveness in the map perception process. Both hue and value were similarly compared. Bertin's three map reading levels were incorporated into the study to measure the level(s) at which the maps were successfully utilized. The majority of the questions were prepared for the intermediate and superior map reading levels since this is where bivariate choropleth maps were designed to excel. Familiarity with the two-variable choropleth map design was another factor examined. The study also examined whether those students more advanced in their academic programs obtained better results. The results strengthened and substantiated the idea that two-variable choropleth mapping is indeed a viable technique for both the cartographer and the map user. No one design was statistically proven to be the most successful overall, since the experimental questionnaire was answered competently by the subjects regardless of the map design they were randomly

assigned. The results showed that subjects could answer questions accurately at all three map reading levels. No significant difference in effectiveness was found between black and white patterns nor with hue and value progressions. As the participants worked with and learned how to interpret the required information from the experimental maps, their results improved significantly.

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CHAPTER 1

INTRODUCTION

Background

In recent years with the accessibility of computers to researchers for data analysis and graphic output, interest in multi-component quantitative mapping has increased. Such accessibility has hastened the need to comprehend and execute viable statistical mapping methods. Various schemes have been devised by researchers in geography and other disciplines to display multi-component or multi-variate distributions. Chang (1982: 95) defined multi-component quantitative mapping as the 'mapping of two or more quantitative variables so that their inter-relations can be studied and subsequently utilized for such purposes as classification and regionalization.' The multi-component quantitative mapping method selected for further research was the two-variable choropleth map. This method was designed to enable the map reader to discern the spatial distributions of the two variables and the correlation between them. One major challenge for cartographers is to design a multi-variate map* enabling the percipient to extract information accurately, thus ensuring good cartographic communication.

Thematic maps displaying geographical data in a statistical map format, which is one manifestation of the statistical trend in cartography, are being produced by many agencies including the U.S. Bureau of the Census and the World Bank. Since the two agencies mentioned are both large establishments whose publications are numerous and well distributed, any innovative mapping technique they implement will be noticed, duplicated and popularized. Although

*The following four terms were used interchangeably throughout the thesis to preclude the monotonous repetition of a single selected description; [a] multi-component, [b] multi-variate, [c] two-variable, and [d] bivariate. Multi-component and multi-variate were interpreted to mean two or more variables, while two-variable and bivariate clearly signified only two variables. Since this research involves the studying of two-variable choropleth maps, all four terms legitimately apply. Additionally previous researchers, as will be demonstrated later in the literature review, [Chapter 2], have selected these terms when describing this mapping technique.

there are many ways to display information to show correlation between variables, each agency devised a greatly different symbolization scheme or conceptual design. The symbolization scheme selected by the U.S. Bureau of the Census to represent the various class intervals was color. The World Bank used a combination of color and black pattern. Since choroplethic bivariate mapping is a relatively unfamiliar and complex mapping method, the map reading tasks become very legend-dependent. Both the U.S. Bureau of the Census and the World Bank used a cross reference or matrix legend, although they varied in size. This type of legend superimposes the two single distributions to create the third or combined category. Since there are more studies in the literature dealing with maps produced by the U.S. Bureau of the Census, this study will reflect that emphasis.

As a result of the two-variable choropleth maps being designed and published by the two previously mentioned prestigious agencies, researchers (Olson, 1975, 1981; Mersey, 1980; Wainer and Francolini, 1980) commenced examining their readability, especially concentrating on how much information the map reader could obtain. These three researchers used test maps obtained from the above mentioned agencies and/or created their own to resemble them.

Mersey (1980), Carstensen (1982) and Eyton (1984) began to research the viability of alternate designs. Only the first two authors conducted experiments, while Eyton's work currently is solely theoretical. Mersey's (1980) test designs in Experiment II of her thesis were based on a 3x3 matrix legend. Carstensen (1982) used a crossed-line, continuous-tone approach, while Eyton (1984) presented the theoretical application of four, complementary-color map designs.

The Problem

Two-variable choropleth maps are becoming increasingly prevalent as a result of the demand to portray quantitative information in an informative manner. Research reviewed to date has not favored conclusively any one particular design. Instead, there is every indication that this mapping method is flexible graphically to the cartographer and readable to the percipient. Still, new conceptual designs require development and testing in order to pursue in detail the extent of the two suppositions of graphic flexibility and map user readability. Moreover with the results from numerous experimental tests, the map reader can be presented, with confidence, the statistical map that conveys the required information most accurately, therefore most acceptably. Statistical maps have re-emerged as an important analytical method since computer analysis and graphics have become fairly common.

A map is an invaluable communication device because it shows the geographical distribution of variables. Wainer and Francolini (1980: 82) stated cartographers and statisticians have a common concern and that is how to display statistical information in a geographic context. Generally, people find it easier to comprehend a map rather than columns of data. Statistical maps visually emphasize the distribution of tabular data of selected geographical areas. This allows geographic patterns that are often obscure in tables and might be overlooked, to become apparent (Klove, 1967: 192). Throughout the history of statistical mapping, interest in creating innovative designs and the experimentation of their effectiveness has varied. Beniger and Robyn (1978), and Fienberg (1979) have traced the history of quantitative graphics as a significant analytical tool. Mersey (1980) at the beginning of her thesis demonstrated by the use of actual two-variable choropleth maps, the numerous graphic design options available to the cartographer, and highlighted the fact that historically this map design has been re-discovered on separate occasions.

Examining the research conducted by the previously mentioned authors in the background section, some conclusions have been agreed upon together with identified areas for further theoretical expansion. Olson (1975) discussed the role of color on two-variable choropleth maps in detail. In Olson's (1981) research, the readability of the bivariate maps produced by the U.S. Bureau of the Census was examined. These maps contained approximately 1000 statistical units, a 4x4 matrix legend, and consisted of 16 distinct colors. Although the symbolization scheme had a definite, organized arrangement, the map users were unable to detect it. Since this mapping method is legend-dependent, a more visibly coordinated symbolization scheme should be designed and studied.

Of the subjects participating in Olson's (1981) experiment, very few of them previously had used two-variable choropleth maps. The results of the study indicated that when the participants were educated graphically or the principles of the mapping method were explained and understood, subjects using the bivariate maps found them interesting to work with and began to interpret the correlation between the mapped variables.

Wainer and Francolini (1980) compared a two-variable choropleth map with the corresponding two univariate maps, at the elementary** map reading level (Bertin, 1983), to determine which mapping technique was superior in terms of accuracy and response time taken by the subjects to answer the questions. In short, subjects using the two univariate maps responded more proficiently. Since two-variable choropleth maps were designed to show the geographic distribution of the two single variables and the correlation between them, future studies must include more questions at the intermediate and superior map reading levels before a more definitive statement about the mapping method can be presented. Once

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**Bertin [1983: 141] specified three levels of map reading: 1] elementary level, 2] intermediate level and 3] overall level. In the literature the 'overall level' of reading has subsequently been referred to as 'superior level' [Wainer and Francolini, 1980: 84, Mersey, 1980: 9]. The term 'superior level' will be used in this research. The three reading levels are defined as follows:

1. Elementary Level - At this level the percipient deals with one or two components strictly at a specified place. No consideration is given to trends that might be readily apparent nor to the correlation between the two variables.

2. Intermediate Level - At this level the percipient examines the existing trends of either one or both of the components. Again no consideration is given to the correlation between the two variables.

3. Superior Level - At this level the percipient studies the correlation between both components by region or considers the complete map.

again participants had trouble working with the legend on the U.S. Bureau of the Census' maps because of the complex color scheme. Also, it should be noted that these particular experimental maps contained a noticeably smaller number of statistical units than the test maps used by Olson (1981). Wainer's and Francolini's (1980) test maps were comprised of approximately 200 statistical units.

Mersey's (1980) research consisted of two experiments. Experiment I dealt with maps produced by the U.S. Bureau of the Census to determine, like (Wainer and Francolini, 1980: Olson, 1981), which mapping technique was better, the bivariate map or the corresponding two univariate maps. The test maps contained approximately 172 statistical units. Although questions at all three levels of map reading were included in the questionnaire, only one was at the superior level. The result was that once again subjects answered questions more accurately with the two single variable maps. Nevertheless when the results were examined further it was found that at the superior level of reading, the composite map started to excel.

Six test maps were designed for Mersey's (1980) Experiment II. All symbolization schemes were developed on a 3x3 matrix legend and contained approximately 100 statistical units. Of the six alternate designs developed, two resembled those from the U.S. Bureau of the Census, one imitated the World Bank design and the remaining three conceptual designs had never been examined experimentally. Mersey (1980) once again incorporated all three map reading levels in her questionnaire. Of the six alternate designs tested, no one design was superior overall in communicating information. In fact, they were all used by the subjects with a great deal of proficiency. Also, it was determined that once the theory behind the mapping method was explained to the map reader and they worked with the maps, their results improved noticeably.

Carstensen (1982) conducted several tests to determine the feasibility of incorporating crossed-line, continuous-tone shading patterns on bivariate maps to show correlation mapping. These test maps were produced using incremental plotters and various computer-assisted techniques. In brief the crossed-line, continuous-tone shading method was successful in producing significant results. The experiment showed that people could determine the mapped positive and negative correlations once they became familiar with the mapping method. It should be remarked that the experimental maps consisted of nine statistical units. Although this mapping technique was successful there were negative aspects. These maps lacked color which people seem to prefer, and the line patterns were often fatiguing to the eyes.

Objective

The overall objective of the study was to examine the two-variable choropleth mapping method to determine its readability to the percipient and graphic design flexibility to the cartographer. As already discussed, two-variable choropleth maps were designed to portray the spatial geographic distribution of two single distributions and the correlation between them. The utility and validity of this design will be analyzed based on the degree to which subjects can interpret correctly the information displayed on the map given the intended purpose of the design.

To accomplish the overall objective, four conceptual designs were created on a 4x4 matrix legend (Appendix I - A, B, C, D). The four graphic design elements used were the combinations of black pattern, white pattern, ordered hue, and unordered hue. In total six primary and one secondary objectives were set out and are listed below:

PRIMARY OBJECTIVES

1. The first set of graphic design variables to be studied were changes in pattern color. The experimental designs in past studies consisted of variations in hue, value, and pattern, where pattern was consistently black. The pattern selected for this experiment was white or reverse and was compared to maps with black patterns.

2. The second design components to be tested were hue and value. Hue is generally referred to as an unordered arrangement of color because

subjects cannot spontaneously identify its quantitative value. The color spectrum has a well defined order but most people are not familiar with it (Wainer and Francolini, 1980: 83-84). However, change in quantitative value is an easy and accepted method for denoting the magnitude of a distribution. This situation is called an ordered arrangement. Hue and value were examined to determine if the unordered and ordered arrangements effect map comprehension.

3. The level of map reading at which a percipient interprets the two-variable choropleth map is of great importance because it demonstrates this mapping method's utility. Bertin (1983) devised three map reading levels which were incorporated in the experimental questionnaire. Two-variable choropleth maps were designed to excel at the intermediate and superior map reading levels, so the study sought responses at the intermediate and superior map reading levels. Of the 32 questions in the task-specific questionnaire only two were designed for the elementary reading level.

4. An important point to remember is the majority of students have never utilized choroplethic bivariate maps previously. It has been determined from earlier studies that once subjects become familiar with this mapping method, they could quite effectively extract the required information. Consequently, learning effects were one positive aspect of the map interpretation/communication process and therefore were analyzed.

5. Four two-variable choropleth maps were created for this experiment to determine which design(s) was more effective in terms of its readability to the map user. These four designs previously had not been tested.

6. This research continued to examine if the more formally educated map readers (i.e. people with more university education) obtained significantly better results.

SECONDARY OBJECTIVE

1. Previous results showed that subjects could interpret the information very acceptably from maps with a 3x3 matrix legend (Mersey, 1980 - Experiment II). Since the U.S. Bureau of the Census published maps containing a 4x4 matrix, it was decided to create the symbolization scheme based on a 4x4 matrix legend. The 4x4 matrix legend increased the design complexity overall. A comparison of the results obtained from Mersey's (1980)-Experiment II with the 3x3 matrix legend and the experimental maps in this present study with the 4x4 matrix legend will be made.

In summary the research consists of four conceptual designs composed of the following combined graphic elements - (1) value with black pattern, (2) value with white pattern, (3) hue with black pattern, and (4) hue with white pattern - to be used in conjunction with a questionnaire designed to incorporate Bertin's (1983) three levels of map reading to comprehend fully this particular mapping method's capabilities. The questionnaire can be found in Appendix I - E.

Methodology and Procedure

SUBJECTS. The sample group for this experiment was 120 university students. Four test groups consisting of 30 subjects each examined one of the four alternate designs. Subjects with varying years of university and taking courses in Geography and Earth Sciences, were randomly selected to participate.

EXPERIMENTAL DESIGN. The total study consisted of four experimental maps and a task-specific questionnaire. The participants worked with only one experimental map in order to eliminate any bias towards another design by increased learning effects. Consequently this research was a between-subjects design.

All experimental design alternatives were compiled on the identical base map of Prince Edward Island. The base map was divided into five regions and contained a total of 43 statistical units. The questionnaire was composed of four distinct parts and had a total of 32 questions. The questions were identical but their order of presentation varied. Subjects received the experimental questionnaire that was organized one of two ways; 1) Part 1, Part 2, Part 3, and Part 4, or 2) Part 4, Part 2, Part 3, and Part 1. All four parts of the questionnaire had a specific time limit that had been determined previously in a pretest. Names were not recorded, and it was stressed that it was the mapping method being tested and not their ability to answer map reading tasks.

PROCEDURE. The test materials consisted of identical booklets containing an introduction to bivariate mapping, the questionnaire and one test map.

Subjects were asked to supply personal data, i.e. age, sex, year of university, major field of study, number of courses taken in cartography and to indicate if they were colorblind. Pertaining to the colorblind issue, subjects were to indicate one of three options. Either they were: (a) colorblind, (b) not colorblind, or (c) uncertain. Of the 120 students tested, not one chose the third option. People who were colorblind were not tested.

The test maps were randomly distributed to the subjects, i.e. in a classroom all four symbolization schemes were distributed to control the possible copying of answers from one subject to another. Subjects were explicitly instructed when to start and stop each section and were not permitted to study the other questions if they completed a particular section quickly. The experiment took 40 minutes to conduct. Further enquiries concerning the overall objectives of the research were answered, if necessary, after each group had completed their respective experiment.

In total the thesis consists of five chapters. Chapter 1 has introduced the background, problem, objectives, and methodology and procedure of the research. Chapter 2 will review the pertinent literature and research conducted to date. Chapter 3 will deal with the design of both the experimental maps and the task-specific questionnaire, the experimental method, as well as the rationale for the applied methodology. Chapter 4 will contain the statistical results of the experiment. Presented in Chapter 5 will be the discussion and concluding remarks concerning the experiment. Lastly, it would be advantageous for the reader to consult Appendix I in order to become familiar with the four alternate designs and the experimental questionnaire.

CHAPTER 2

RELATED RESEARCH

The Appearance of the Two-Variable Choropleth Mapping Method

The two-variable choropleth mapping method has a distinct and traceable history (Beniger and Robyn, 1978; Fienberg, 1979; Mersey, 1980). Various symbolization schemes have been employed, (i.e. combinations of color and color, pattern and pattern, or color and pattern), without prior analysis or experimentation as to their competence. These maps were designed and published without particular scrutiny as to what information the map reader actually obtained. The first maps that sparked much academic discussion were the color statistical choropleth map series produced by the U.S. Bureau of the Census entitled (Meyer et al., 1975: 103, 107, 108):

1. "Distribution of Older Americans in 1970 Related to Year of Maximum County Population",

2. "Interrelationships of Education Attainment and Per Capita Income", and

3. "Average Value of All Products Sold to Size of Farm".

Map number two was selected as an illustration and was reproduced in black and white (Figure 2.1) although it was published in color originally. Color reproduction of the map was not determined to be necessary since two-variable choropleth maps produced by the U.S. Bureau of the Census are available to interested readers in numerous journals. A partial reference list containing three sources follows:

(1) Meyer, M.A., Broome, F.R., and Schwietzer, R.H., Jr. *Color Statistical Mapping by the U.S. Bureau of the Census.* The American Cartographer, 1975, 2(2), 100-117.,

(2) Olson, J. *The Organization of Color on Two-Variable Maps.* In Auto-Carto II. International Symposium on Computer-Assisted Cartography, 1975., and

(3) Olson, J. *Spectrally-Encoded Two-Variable Maps.* Annals of the

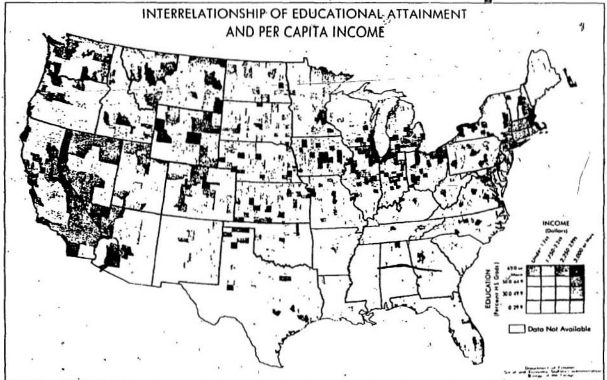


FIGURE 2.1 U.S. Bureau of the Census bivariate map (Meyer et al., 1975: 107)

Association of American Geographers. 1981, 71(2), 259-276.

The sample bivariate choropleth map (Figure 2.1) enabled the the cartographer to portray three spatial distributions simultaneously, i.e.,

A) Education Attainment,

B) Per Capita Income, and

C) the interrelationship between (A) and (B).

These census maps are spectrally-encoded (Olson, 1981: 259) because the three primary colors - cyan, magenta, and yellow - are used to create hues to represent three distributions. Figure 2.2 depicts the symbolization scheme selected to represent the quantitative data.

The literature review has been subdivided into two sections. First, not long after the U.S. Bureau of the Census published the bivariate maps, researchers started to examine their readability and utility. This research is reviewed in the first section. Second, several years later studies that advance and improve the two-variable choropleth mapping technique began to appear. The last section deals with this research.

Initial Reaction to and Examination of the Two-Variable Choropleth Mapping Method

After this bivariate mapping method had been published by the U.S. Bureau of the Census, researchers started to investigate the efficacy of this design. It should be noted that prior to Olson's (1975, 1981) published papers, the only information available to cartographers concerning the validity of these maps were their personal opinions and those exchanged with their colleagues. These two-variable choropleth maps contained approximately one thousand statistical units that varied in size from relatively small to reasonably large. The graphic component selected to represent each mapped variable (i.e. Income and Education) was color. Both Income and Education were divided into four classes creating a 4x4 matrix legend. The concern expressed verbally by cartographers was that the maps were complex and map users could very well find it difficult to extract the decoded information.

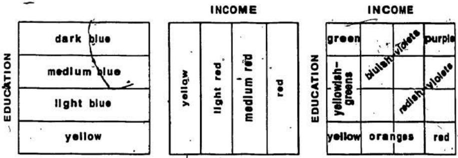


FIGURE 2.2 Color composition of the map entitled "INTERRELATIONSHIP OF EDUCATION ATTAINMENT AND PER CAPITA INCOME" (after Carstensen, 1982: 55).

Olson's (1975: 289) study examined in detail the critical role of color organization on bivariate maps. Colors used to encode information on a two-variable choroplethic map must be utilized in a logical and coherent manner. They must be selected to display the magnitude of the distribution for each separate variable while concurrently depicting the correlation between the two mapped components. Overall, the advantages of using color as a symbol are listed:

1) it makes the map aesthetically appealing to the map reader,

2) color can be employed to clarify information, and

3) it is another component that the cartographer can use in designing complex symbols to portray additional information.

Further research by Olson (1981) addressed the degree of readability of the bivariate choropleth maps produced by the U.S. Bureau of the Census. Four experiments were designed to study the effectiveness of these particular bivariate maps. Olson's (1981) Experiment 1 dealt with the symbol system, specifically the meaningful organization of color on a spectrally-encoded legend by the map user.

Subjects were presented with nine or sixteen color chips, based on the Census Bureau's color scheme modified slightly to enhance the transition of color, and asked to organize the colors in a logical manner. It was hoped that some of the subjects would replicate the color symbolization scheme employed by the Census Bureau. All 27 subjects produced unique 3x3 and 4x4 matrix legends, none of which matched the original or control legend scheme. Nonetheless, when presented the control symbolization scheme, subjects reiterated that it definitely appeared organized. It should be mentioned that this researcher thinks additional map designs employing color need to be tested. It is important to utilize the graphic variable color since color does have connotative merits and map readers generally find it aesthetically appealing.

For Olson's (1981) Experiment II subjects were required to judge the spatial correlation between the variables using the bivariate maps and the corresponding two univariate maps. To ensure that participants fully understood the correlation concept, time was taken to explain it thoroughly in elementary, non-technical language. The test stimuli were not actual published maps, but a fabricated normal distribution superimposed on a 10x10 dimensional grid. Pattern sequences were selected based on preset levels of both autocorrelation and correlation. Furthermore, map complexity varied since test stimuli were based on the 4x4 and the 3x3 matrix legend. Subjects had two different tasks to complete. Firstly, they were requested to examine the black and white maps of the two separate distributions and select the one that more closely resembled the referent map. Secondly, participants were presented with two bivariate test stimuli and were to determine which of the two distributions demonstrated the greater degree of correlation.

Students using the pair of univariate maps performed better than those answering the questions with the bivariate maps. It appeared that many of the subjects using the less familiar bivariate maps were guessing and consistently selecting the incorrect answer. Correlation between the variables was not readily apparent. However, the people who eventually understood this technique did obtain slightly better results - although not statistically significant - working with the two-variable maps as opposed to the two univariate maps. In conclusion this research indicated that learning the purpose of the selected mapping method in addition to comprehending the graphic - (how to obtain information from the graphic) - was required when introducing and examining an unfamiliar map design. Correlation on actual bivariate maps warrants further examination.

Olson's (1981) Experiment III examined the type of information people extracted from the two-variable choropleth maps from written essays, while Experiment IV addressed the subjects' perception of the map from questionnaires. The same group of participants were used for both experiments. Participants were placed in one of seven groups. Six groups were assigned bivariate maps and the remaining group, number seven, two univariate maps. The first six groups were further subdivided by issuing half the subjects maps with a short explanatory note stating the purpose of the map, while the other half was given just the map. The results from the participants' essays were as follows:

1) very seldom did anyone mention the interrelationship between the variables,

2) hardly any map readers discussed the pattern of individual variables, and

3) the regionalization of similarly shaded areas was discussed most frequently.

In Olson's (1981) concluding experiment, Experiment IV, it was discovered that subjects found the spectrally-encoded two-variable maps to be aesthetically appealing. While the univariate maps were given a high rank for readability, the spectrally-encoded bivariate maps were seen as more innovative and interesting to work with. These findings give subsequent researchers incentive to continue studying the merits, and eliminating the stumbling blocks in the mapping method. The ultimate goal is map designs that are effective in communicating information.

From the experimental observations and results it was concluded that the maps produced by the Census Bureau did communicate information to the map reader, but they adequately failed to indicate correlation. Map users appeared to have major difficulty in visualizing the component colors that created the two-variable maps, and therefore interpreted them the same way they would interpret a univariate map. When the correlation between the variables was mentioned, it was by subjects working with the maps that included a short explanation describing the purpose of bivariate choropleth mapping.

Multi-component quantitative mapping is complex, and researchers are seeking methods to effectively display statistical data on a geographic background. Monmonier (1977: 33) stated that quick information retrieval on these types of maps does not exist because map readers must deal with a large number of categories and a complex legend. He advocated informing the map reader that a map series exists. Since a map will depict only one variable at a time, the number of maps presented to the map reader will depend on how many variables were mapped. The map reader could then examine the geographical distribution with little distraction. Monmonier placed the responsibility on the author of the paper that contains the map(s) to explain or expound upon the relationship between the variables in their text or during an oral presentation. Separate maps containing a single variable simplifies communication but fails to adequately show the interrelationship between variables which could be quite significant, and which could provide much more meaningful relationships.

Wainer and Francolini (1980) obtained two-variable choropleth test maps from the U.S. Bureau of the Census to study the effectiveness of the design by assessing how much information people obtained from them. These maps contained approximately 200 statistical units and a 4x4 matrix legend. Their study of the two-variable choropleth map consisted of two experiments whose basic aims were:

1) to determine what type of mapping scheme, bivariate or two single univariate maps, was superior by questioning subjects at the elementary

level of reading, and

2) how adept people were in learning complex color schemes and testing this performance over time.

Many researchers in two disciplines, geography and statistics, (Bertin 1983, 1981; Mersey, 1980; Carstensen, 1981; Fienberg, 1979; Cleveland, 1984a, 1984b), have commented, with much conviction, on the necessity of having more structured experiments using language and theoretical concepts that pertain to graphic displays. In turn, standardization of graphic vocabulary and elucidation of theoretical concepts would facilitate research by increasing the understanding of graphic communication. Wainer and Francolini (1980) dealt with some of these concerns by actively attempting to incorporate Bertin's (1983) theory and vocabulary of graphic displays in their research. Three levels of interpretation for graphical displays were specified in the experiment as outlined in Bertin's (1983: 141)*** 'Semiology of Graphics': 1) elementary level, 2) intermediate level, and 3) overall level.

The significance of Bertin's theoretical concept of map reading levels requires further elaboration. The two-variable choropleth mapping technique was designed to show the geographic distribution of two separate variables, (i.e. income and education), and the interrelationship or correlation between them. By applying Bertin's three levels of map reading the researcher can ascertain how successfully the map design fulfills its purpose from depicting simple, specific amounts of information i.e. elementary map reading level, to trends in a region i.e. intermediate map reading level, to the most important design component which is to show the correlation between the two variables or the superior map reading level.

Although the definitions have already been given in Chapter 1, page 4, they

*** Bertin[1983] 'Semiology of Graphics' is the English translation of Bertin's[1973] 'Semiologie Graphique'.

will be reiterated here along with a sample question to help clarify the concepts. Bertin's three map reading levels are defined as follows:

1. Elementary Level - At this level the percipient deals with one or two components strictly at a specified place. No consideration is given to trends that might be readily apparent nor to the correlation between the two variables. The percipient in answering the following question must search for the bivariate symbol that represents the specific combination of Income and Education. (Part 1, Question 1. In which region does the combination of Per Capita Income $20,000 or more and Education 85.0 percent or more occur most often?)

2. Intermediate Level - At this level the percipient examines the existing trends of either one or both of the components. Again no consideration is given to the correlation between the two variables. (Part 2, Question 1. The map below indicates five distinct regions. Label each region with a L(Low), M(Medium), H(High) or VH(Very High) to indicate the appropriate level of Per Capita Income dominating the region....)

3. Superior Level - At this level the percipient studies the correlation between both components by region or considers the complete map. (Part 3, Question 4. Lastly, examine the total map and select the one statement that best describes the dominant relationship between Per Capita Income and Education overall....)

To satisfy aims one and two, reiterated below, Wainer and Francolini (1980) conducted two experiments. The aim of Experiment 1 was to determine what type of mapping scheme, bivariate or two single univariate maps, was more effective by questioning the participants at the elementary level of reading. Experiment II was designed to ascertain how adept people were in learning complex color schemes and testing this performance over time.

In Experiment I two separate experimental booklets were given to 16 psychology graduate students. One booklet contained nine pairs of univariate maps while the other one consisted of the nine corresponding bivariate maps. The subjects were required to determine at the elementary reading level the status of the two variables at the designated location. Half of the students worked first with the univariate maps while the remaining eight subjects were given the bivariate maps. The number of errors and the response times were recorded in order to determine which mapping technique was superior in terms of accuracy and response time. The results indicated that subjects performed more proficiently with the univariate maps than with the bivariate maps. It must be remembered that univariate maps were more familiar to subjects than bivariate maps. Generally, in order to obtain adequate results with an unfamiliar mapping method, i.e. choroplethic bivariate mapping, subjects must possess an understanding of the mapping technique. This implies practical work until proficiency has been achieved.

Experiment II was conducted several weeks following the first experiment using half of the subjects who participated in Experiment I. The identical experimental procedure was repeated except that a fifth trial was included. In this fifth trial the legend was removed and the students were required to answer questions based solely on what information they memorized previously from the legend. The removal of the legend was not a surprise since the subjects were instructed that the legend would be absent from the final test map. The degree of accuracy was not acceptable to Wainer and Francolini (1980) at the elementary level.

It should be emphasized that only 16 university students participated in the first experiment, and half of them returned for the second experiment. Although the authors were not impressed with the results, a larger sample size should have been utilized in order for their results to have full impact. Otherwise, all they can confidently discuss is a possible trend. All in all, Wainer and Francolini (1980: 91) stated that even though their results at the elementary map reading level were considered less than impressive, it does not preclude the fact that at the intermediate and superior map reading levels these maps could excel. Obviously, more research employing experimental questions at the two higher levels needs to be conducted for a fuller evaluation.

Lastly, in their discussion Wainer and Francolini (1980) pointed out the necessity of displaying data according to a logical and apparent symbol-value relationship. More studies creating alternate designs with this principle in mind are required. One of their recommendations (Wainer and Francolini, 1980: 91) for subsequent study was the use of pattern for one variable and increasing the value of one color for the second mapped component. These concerns and suggestions will be implemented in my experimental research.

The overall objective of Mersey's (1980) study was to augment the current level of knowledge concerning the bivariate choropleth mapping technique, specifically the various symbolization schemes and the map readers' response to them. The first experiment compared the map users' ability to extract the required information from a bivariate map and two univariate maps of the identical distributions. The aim of the second experiment was to determine which symbolization schemes, if any, were more effective in communicating specific information.

Mersey (1980) designed her questionnaire in Experiment I to incorporate all three levels of map reading requiring subjects to examine the distribution of one or both variables. However, the majority of the fifteen questions were at the elementary and intermediate map reading levels. Only one superior level question was included. For nine of the questions, subjects were directed to a maximum of five numbered statistical units. This, in my opinion, facilitated interpreting the information displayed on the maps.

On the basis of the test map(s) issued, participants were placed in one of three groups. The bivariate map was given to one group of 28 students, the two univariate maps of the identical distributions comprised another group of 27 students, and the last group of 26 students received all three maps. The inclusion of the third group was taken from Olson's (1981) study when it was concluded that the two-variable choropleth map would probably be most effective when accompanied by the two single variable maps. All 81 subjects used the identical questionnaire in Experiment I. Finally, color xeroxes of the bivariate map and the two univariate maps produced by the U.S. Bureau of the Census served as test maps. These maps were composed of approximately 172 statistical units and had a 4x4 matrix legend (Figure 2.3).

The results from Mersey's (1980) study, Experiment 1, concur with those of Olson (1981), and Wainer and Francolini (1980) in that subjects answered questions more accurately with the two single variable maps. When the results were examined further it was found that at the superior level of reading, subjects utilizing the composite map started to excel. The problem here is that only one question at the superior reading level was included in this questionnaire. This is a concern since one of the major proponents of the two-variable choropleth map design is that these maps illustrate correlation, and superior level questions examine the correlation between the two mapped components. Further research needs to be conducted exploring the effectiveness of these maps at the superior reading level so conclusive statements can be issued concerning the validity of the mapping design. Lastly, the third group, who were given all three maps did not perform significantly better. Therefore, Olson's (1981) statement that it might be advantageous to include the two single variable maps with the bivariate one may be not useful.

Advancing and Improving the Two-Variable Choropleth Mapping Method

The second section of the literature review discusses various researchers' ideas and attempts at advancing and improving the bivariate choropleth mapping technique. Fienberg's (1979) research was an evaluation of the graphical trends in the discipline of statistics. Of particular interest to my research were the comments concerning the two-variable choropleth mapping technique. He explained the purpose and design of this mapping method, as well as offered some concerns pertaining to the readability of the U.S. Bureau of the Census produced two-variable choropleth maps. Most significantly, Fienberg (1979: 176) identified five issues for future researchers that required further analysis in order to help refine the bivariate choropleth mapping method:

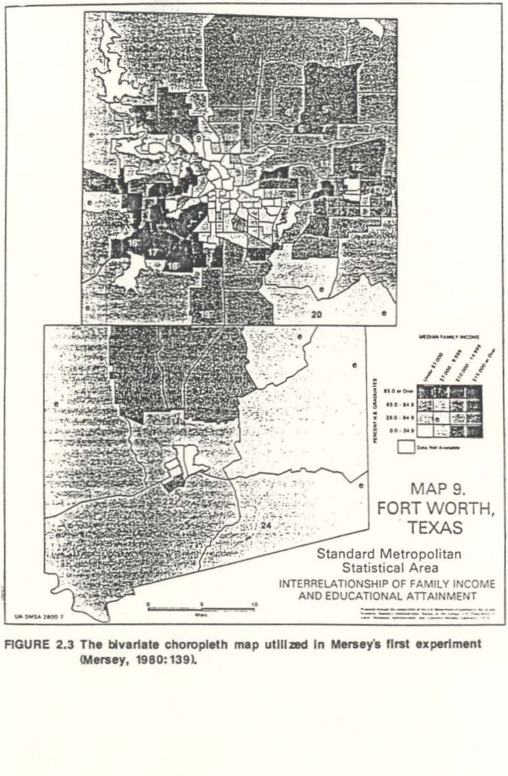


FIGURE 2.3 The bivariate choropleth map utilized in Mersey's first experiment (Mersey, 1980: 139).

1) selection of class intervals,

2) selection of colors,

3) total number of required classes,

4) to determine what display technique or symbolization scheme was superior - pattern and one color or a two color scheme - and

5) to determine if individuals could extract information more accurately and efficiently from the two single variable maps or the two-variable statistical map.

For this researcher's experiment issues 2, 3, and 4 will be addressed. It should be mentioned that Fienberg's (1979: 176) third issue (i.e. total number of required classes) was interpreted as the number of statistical units.

Symbolized information on a map must be decoded by the map reader in order for the map to be of any benefit. The selection of colors for meaningful and/or informative bivariate choropleth maps was examined by Trumbo (1981). Trumbo (1981: 225) stated that his approach in adding to the development of a theory for color selection on bivariate maps was a general one that could be applied to most mapping situations of this nature. Emphasized strongly was the need to select a color scheme that highlighted the attributes of the data. Trumbo (1981) has articulated four principles that reflect this emphasis:

1. Order - colors selected to represent the mapped components should be chosen to reflect the apparent order or number of levels in the data.

2. Separation - it is important that noticeable differences in the data are accentuated.

3. Rows and Columns - in order to retain the uniqueness of the two separate distributions, the colors selected should not obscure each other.

4. Diagonal - if the researcher wished to highlight the positive correlation, the colors should be chosen to emphasize the diagonals.

In the discussion of the paper, Trumbo (1981) proposed color schemes based on these four theoretical considerations. However, none of these color schemes were empirically tested, so a definitive concluding statement as to which one(s) were the best was impossible to make.

Continuing to explore the graphic design option of using color to represent two mapped components, Eyton (1984) in his article discussed an innovative bivariate map design that he produced, the complementary-color, two-variable map. In keeping with the cartographic and statistical principles for a two-variable choropleth map, the complementary design also depicted the correlation between the two mapped variables in addition to the distribution of the two single variables. A total of four maps were presented along with a detailed discussion of the advantages and disadvantages of each design. The descriptions of the four maps were taken from (Eyton, 1984: map supplement accompanying the article):

"Plate I -- Complementary-color, two-variable map based on a rectangular legend arrangement

Plate II -- Unclassed complementary-color, two-variable map using linear scaling

Plate III -- Unclassed complementary-color, two-variable map using logarithmic scaling

Plate IV -- Complementary-color, two-variable map based on a rectangular legend arrangement combined with an equiprobability ellipse."

It should be noted that, in fact, Plate IV was both a compromise and a combination of what was deemed best from the proceeding maps according to (Eyton, 1984: 486, 489).

Eyton (1984: 479) was of the opinion that the color scheme used by the U.S. Bureau of the Census for two-variable maps should be simplified to facilitate map interpretation. The first of four maps presented was a complementary-color, bivariate map structured on a 3x3 matrix legend. It was felt since two variables were being mapped, only two complementary colors would be needed to represent the data. Figure 2.4 illustrates the legend arrangement of this particular

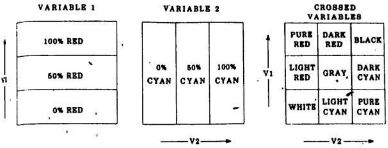


FIGURE 2.4 Eyton's first legend arrangement for a complementary-color bivariate map (Eyton, 1984: 481).

complementary-color, bivariate map. The legend arrangement highlights the four corners - the more extreme data values and the diagonal - indicates the positive correlation. The combination of equal values of the two selected complementary colors - blue and red - generates the diagonal colors from white to grey to black. Increase in the income level is illustrated by a red progression, while the increase in educational attainment is shown by a blue progression. According to (Eyton, 1984: 481-482) the main disadvantage of this system is the superimposition of the rectangular legend on a bivariate distribution. He advocates using some form of the line of best fit, i.e. major axis or ellipse.

The second map design was described as the "unclassed complementary-color, two-variable map using linear scaling" (Eyton, 1984: map supplement). This style of map uses the reduced major axis as the line where the whole grey scale from white to black is positioned. To complete the legend symbolization scheme, on either side of the grey scale was placed one of the two complementary colors. The problem here is that numerous tones are created as a result of the continuous scaling, and it becomes difficult for the map user to extract the information.

The third version, the unclassed complementary-color bivariate map was created using a logarithmic scaling. It was felt that by avoiding the data extremes, the number of variations in tone and hue would diminish substantially, thereby making it an easier map with which to deal.

The final proposed map, "a complementary-color, two-variable map based on the binormal distribution" (Eyton, 1984: map supplement) was a concerted effort to amalgamate the positive attributes of the maps previously discussed. This map was deliberately designed to show both extreme values and average values (Figure 2.5). The extreme values were portrayed by one of four colors from the

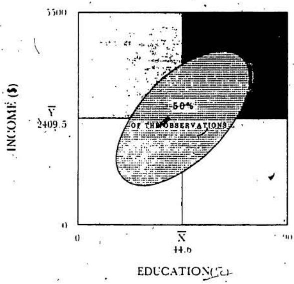


FIGURE 2.5 Eyton's final test legend design (Eyton, 1984: map supplement).

2x2 matrix, and the average values were represented by the fifth class - the equiprobability ellipse of 50 percent.

In conclusion, it should be noted that these four proposed designs have not been subjected to experimental testing. Consequently, there were no conclusive statements to be issued, only theoretical assumptions, concerning the validity of these particular four unique map designs. Since the article was organized in such a way as to highlight the fourth map design, which was in essence the culmination of the attributes of the proceeding maps, Eyton showed it to interested students and oolleagues for approval. Despite the totally unfamiliar legend design, the people seemed to be able to comprehend the map. As a promising sign to Eyton (1984), all the people who looked at the map were in agreement that his innovative design was easier to utilize than a comparable two-variable choropleth map.

In Mersey's (1980) thesis two experiments were conducted. Experiment II was included in this section of the literature review because the objective dealt with advancing and refining the bivariate choropleth mapping technique. Six test maps were designed for Experiment II to determine which symbolization schemes were more effective in communicating information (Figures 2.6 and 2.7). Figure 2.6 shows the graphic composition of the selected symbolization schemes tested, while Figure 2.7 contains one of the six experimental maps. These experimental maps contained approximately 100 statistical units, fairly uniform in size. In addition, the symbolization scheme was based on a 3x3 matrix legend. The sample size for each test design was 32. All subjects answered the same questions concerning the identical geographical area but used only one of the six symbolization schemes. The experimental questionnaire consisted of four sections. The first section dealt with subjects identifying homogeneous regions at the intermediate level of reading. In Section II the participants were asked to indicate the level, (low, medium, high) of each of the designated regions on the map. They only dealt with one variable at the intermediate level of map reading. Section III dealt with the superior map reading level, and subjects were asked questions about the correlation of the two variables in both the legend and the map. Of the six questions posed, five dealt solely with the legend while the remaining one question asked subjects to evaluate the correlation between the two mapped components. Section IV was very similar to Section I. This time the region was

MAP ONE

70 C 10 M	70 C 30 M	70 C 70 M
40 C 10 M	40 C 40 M	30 C 70 M
10 C 10 M	10 C 30 M	10 C 70 M

MAP FOUR

30 Y 7197 Z	10 M 60 Y 7197 Z	30 M 70 Y 7197 Z
30 Y 7108 Z	10 M 60 Y 7108 Z	30 M 70 Y 7108 Z
30 Y	10 M 60 Y	30 M 70 Y

MAP TWO

70 C 70 Y	70 C 30 M	70 C 70 M
30 C 70 Y	30 C 30 M	30 C 70 M
70 Y	30 M 70 Y	70 M 70 Y

MAP FIVE

60 C	60 C 60 Y	60 M 60 Y
40 C	40 C 40 Y	40 M 40 Y
20 C	20 C 20 Y	20 M 20 Y

MAP THREE

60 C 60 Y	60 C 60 Y 7183 Z	60 C 60 Y 7181 Z
40 C 40 Y	40 C 40 Y 7183 Z	40 C 40 Y 7181 Z
20 C 20 Y	20 C 20 Y 7183 Z	20 C 20 Y 7181 Z

MAP SIX

80 C	80 C 40 Y	70 C 80 Y
50 C	50 C 30 Y	40 C 50 Y
30 C	40 C 20 Y	30 C 30 Y

Y = % yellow M = % magenta C = % cyan

Z = Zipatone pattern number.

FIGURE 2.6 Specific graphic composition of Mersey's six test maps (Mersey, 1980: 146).

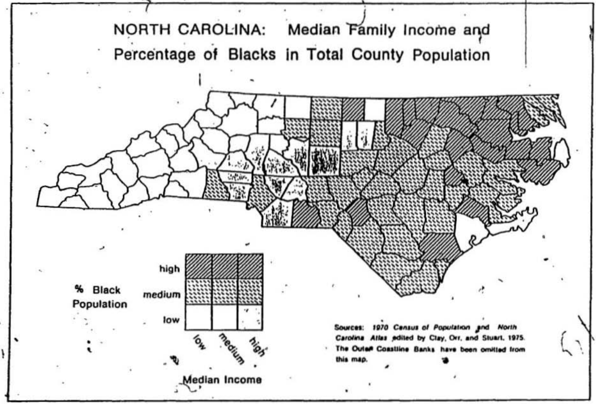


FIGURE 2.7 One of the six two-variable choropleth maps used by Mersey in Experiment II (Mersey, 1980: back pocket of thesis).

specified and the participants were required to interpret both variables at the intermediate map reading level.

Another experimental design factor incorporated into the questionnaire and statistically measured was learning effects. After becoming accustomed to this mapping method, it was hypothesized that the subjects' performance would improve. Hence, a method was devised to measure learning effects - which in this particular circumstance was the difference in the number of correct responses between questionnaire sections completed first and last. Sections I and IV were alternated, half the subjects worked first with Section 1 and the other half with Section IV.

The experimental results for Experiment II were very interesting. The hypothesis stating that the subjects' performance would improve after becoming familiar with the two-variable choropleth mapping technique was indeed supported. It was also determined that the more experienced map users obtained better results. Further analysis indicated that of the six alternate designs tested, no one design was superior overall in communicating information. All in all, participants were able to use each design with good success. However, questions answered at the superior map reading level (i.e. most of them dealt with the legend) were not responded to as accurately. Perhaps decreasing the number of statistical units on a two-variaible choropleth map is one way of increasing accuracy at the highest map reading level.

The six alternate designs created by Mersey (1980): Experiment II consisted of variations in color and pattern, where pattern was always black. Perhaps the combination of color, (value and spectral), with white pattern would ellicit a different, more positive result overall. Lastly, Mersey (1980): Experiment II based her test maps on a 3x3 matrix legend. It would be informative to see if results differ on two-variable choropleth maps with a 4x4 matrix symbolization scheme.

Carstensen (1982) conducted several tests to determine the possibility of incorporating crossed-line, continuous-tone shading patterns on bivariate maps to show correlation mapping. These unique black and white test maps were produced using incremental plotters and various computer-assisted techniques. According to Carstensen (1982: 57) research has demonstrated that map readers have no trouble interpreting continuously shaded maps (Figure 2.8).

The first part of Carstensen's (1982) Experiment One dealt with the questions at the elementary reading level because participants were requested to retrieve a specific value. Twenty-four students were given a sample legend and asked to visually match twenty extracted sections of legend shading blocks (Figure 2.9). The appropriate x and y coordinates of where these blocks would be found in the legend were to be indicated in the space provided. Following this task subjects were asked a question, second part of Carstensen's (1982) Experiment One, that was explicitly designed to ascertain to what degree they coped with and successfully understood the crossed-line, continuous-tone mapping method. Participants were asked to rank three solution methodologies, listed below, in the order of their usefulness:

A) Shading Blackness - the strength or degree of black shading,

B) Line Spacing - the measured distance between the lines considering each axis separately.

C) Box Shape - combining the line spacing of the two separate axis to create a whole unit or box, i.e. the location of both mapped variables.

The three solution methods were significant because they were indicators as to how the map was being interpreted.

Examining the results from the first task of Experiment One, it was apparent that subjects could interpret the crossed-line, continuous-tone patterns at the elementary reading level. Furthermore, it is important to note that the more experienced the students became, as a consequence of working with the test materials, the better the results.

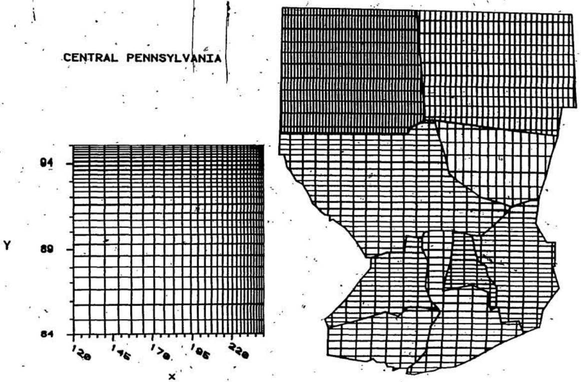


FIGURE 2.8 Crossed-Line, Continuous-Tone bivariate map (Carstensen, 1982: 66).

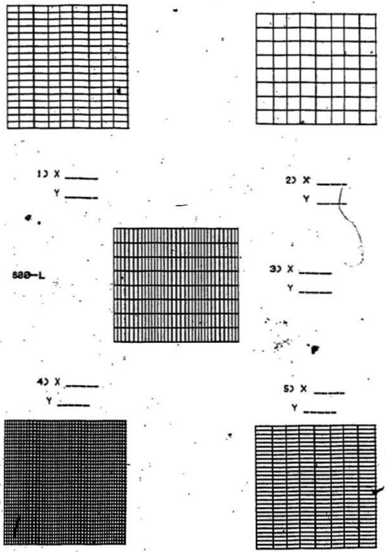


FIGURE 2.9 A sample of Carstensen's test for legend identification (Carstensen, 1982: 59).

Analyzing the subjects' methodological rankings, results from part two, the students selected the box shape (C) to be the most helpful in locating the extracted legend sections. However, it was noted by one student in particular, that all three methods were applied to a varying degree. The significance of selecting the box shape is that at least the relationship between the two variables is being studied in the legend, which is where map comprehension and interpretation commences.

Carstensen's (1982) test number two examined system logic - which was to discover if the crossed-line, continuous-tone mapping method could be duplicated or generated without previous knowledge of the design. The devised test was similar to the one used by Olson (1981). A crossed-line, continuous-tone sample legend was divided into sixteen chips. Twenty-four subjects who previously had not seen the legend were required to assemble the sixteen pieces on two axes, labelled low to high, in a logical manner. From the results it was evident that the chips were not placed haphazardly by the students. Overall many did perceive the shading pattern reasonably well, in fact the legend was replicated exactly by 33 percent of the students who had never seen it before. If mapping symbolism is logical and can be generated with a minimum of specialized knowledge or skill, then it is a major asset and a step in the right direction when creating a new system. Carstensen's results suggest that crossed-line, continuous-tone mapping is such a system.

Experiment III dealt with perception correlation. The purpose of this experiment was to analyze the degree to which the correlation between the variables was perceived, given a time limit of one minute. The time limit was necessary to discourage students from formulating a response based on value retrievals rather than on the perceived visual patterns. Subjects were presented with maps depicting one of three possibilities: 1) a positive correlation, 2) a negative correlation, or 3) no relationship. A sample of the three types of relationships listed above was given to every participant in order to familiarize themselves with the concept of statistical correlation. Once knowing precisely what the three statistical relations resembled, Carstensen (1982) felt confident that the subjects could effectively deal with the assigned mapping tasks. Participants were presented two out of the possible combination of three maps, and were requested to ascertain what type of correlation was mapped. The test maps consisted of nine large statistical units. Since time was a factor, (i.e. the researcher relied on volunteered class time to conduct the experiment), the experimental maps had only nine units. The results confirmed the hypothesis that participants could indeed judge correlation from the crossed-line, continuous-tone maps.

In conclusion the crossed-line, continuous-tone shading method was successful in producing readable correlation maps but there were a few negative aspects. These maps lack color which people seem to prefer, the line patterns are often fatiguing to the eyes of some people, and if a map contains any small areas, it is often impossible to include the necessary number of lines to create the pattern. Carstensen (1982: 69) stated that even though the above negative aspects exist, overall the experimental testing has indicated that the crossed-line, continuous-tone method was a viable multi-component mapping technique.

The main goal of Carstensen's (1984) paper was to determine how subjects interpret variable similarity on two types of bivariate maps: 1) the spectrally-encoded two-variable choropleth map and 2) the crossed-line, continuous-tone map. To accomplish this goal Carstensen required students first to become acquainted with the principle of variable similarity, as he applied it to the mapping situtation. Carstensen (1984: 23) defined variable similarity 'as the degree to which spatially paired values for two variables fall into like positions within their respective distributions.' Forty-one students worked with the spectrally-encoded two-variable map and 33 other students were assigned the crossed-line, continuous-tone map. Both types of maps contained 40 statistical units (Figure 2.10). The crossed-line, continuous-tone maps were enlarged by 50

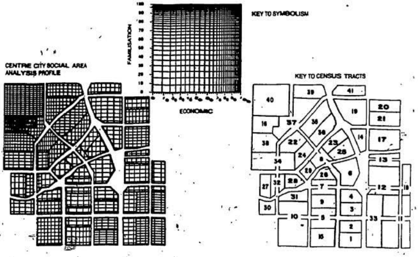


FIGURE 2.10 An example of the test maps used by Carstensen (1984: 24).

percent to alleviate the problem of having to position crossed-line patterns in small zones. Identical instructions were distributed to each of the respective groups.

The mapping task given to the participants was to create and list the tracts that would comprise both an unbalanced and a balanced region. As previously mentioned the concept of unbalanced and balanced**** was explained prior to testing to ensure it was understood by the students. Students were given the number of the zone from which to commence, with the understanding that the

**** Note the words unbalanced and balanced, and dissimilar and similar - i.e. words used to articulate the concept of similarity - are used interchangeable since [Carstensen, 1984: 23-24] employed the first set of terms in his instructions to the subjects and the second set of terms to explain the theoretical significance.

selected zones had to be contiguous to form a region. For both sections of the experimental test, students were only allotted three minutes as a restrictive measure to prohibit them from answering the questions by value retrieval as opposed to visual perception.

The data collected from the experiment were managed as follows. Every time a zone or tract was listed, it was recorded to determine the total number of times that zone was mentioned. A tract had to be mentioned by one third of the participants (i.e. 11 of the 33 subjects using the crossed-line, continuous-tone and 14 of the 41 students using the spectrally-encoded two-variable map) before it was considered to be part of the region. The two types of maps contained the identical data but the graphic presentation was vastly different. Nevertheless, the two groups working with them agreed to a substantial extent on the map or data interpretation. As an illustration, of the nine zones selected between the two map design groups to represent the balanced region, seven zones were commonly listed. Similarily of the 26 zones chosen by consensus between the two previously mentioned groups to represent the unbalanced region, nineteen were commonly selected. Carstensen concluded from these results that the two map designs enabled map users to interpret variable similarity on a consistent basis.

Of all the research reported in this review, the one factor that constantly changes and has the potential to be a deciding factor and influence is the number of statistical units contained in the test maps. For example, the number ranges from approximately 1000, (maps produced by the U.S. Bureau of the Census), to only nine fairly large areas (Carstensen, 1982: 66). Perhaps a limit exists pertaining to the number of statistical units on a two-variable choropleth map that the map reader can process easily.

The literature review highlighted the current state of knowledge and identified questions that required further investigation. Two-variable choropleth maps were determined to be a viable quantitative mapping technique that required further improvements. The research conducted for this thesis continues to advance and improve the bivariate choropleth mapping technique in terms of its readability to the map user and graphic design flexibility to the cartographer. Unanswered questions that started this inquiry are follows.

1. The examination of the literature has shown that pattern was one method selected by cartographers for area symbology. Pattern is a graphic design element that can be used effectively to represent a specific value for an area. However, the color of the pattern used has always been black. The experimental maps for this research will be constructed with black patterns and white patterns. A comparison will be made to determine if subjects find black patterns or white patterns more readable.

2. Color has inherent properties that logically can be applied to symbolization schemes on a map. Since color is an excellent graphic design component that is suited to the portrayal of data, additional schemes with color are interesting and necessary. Previous research has indicated that color schemes are more effective when the map readers can identify a logical color progression. In this study two progressions of color were compared (i.e. hue vs. value) to determine if one was more successful in communication information.

3. Bertin's (1983) three map reading levels have been incorporated into three of the more recent studies because they serve as an excellent guide to determining the amount of information people are obtaining from the bivariate choropleth map design. However, additional testing at the superior map reading level is required since earlier experimentation has not addressed this concept as thoroughly as map reading at the elementary and intermediate levels. It should be remembered that the bivariate mapping method was designed to excel at the intermediate and superior map reading levels.

4. Since the two-variable choropleth mapping method is unfamiliar to most people, they have to be taught the purpose of the design and how to read it graphically. Once people become familiar with the mapping technique, information is retrieved more accurately. The examination of learning effects was incorporated into this experiment to assess the map interpretation/ communication process.

5. The various graphic design components (i.e. hue, value, black pattern, and white pattern) were combined to generate four experimental maps. The resulting four designs previously had not been examined. The next stage was to determine if one or more of the design combinations was more successful in communicating information to the map reader.

6. Previous research seemed to indicate that the more formally educated map readers were able to obtain the most accurate information from this particular

mapping technique. The present study will continue to examine this factor.

7. In this research a symbolization scheme based on a 4x4 matrix was selected because the researcher wanted to work on the more complex case. The results from this study will be compared to Mersey's (1980–Experiment II) that contained a 3x3 matrix legend arrangement.

CHAPTER 3

METHODOLOGY AND PROCEDURE

Introduction

With increasing emphasis being placed on the graphic portrayal of quantitative data, it is important that cartographic designs are relevant and effective. A two-variable choropleth map is one such method. Accessibility of computers to researchers in addition to the numerous statistical, graphic, and mapping packages, make it essential to have demonstrated and proven analytical mapping methods. Although the four experimental maps utilized in this study were produced using mainly conventional cartographic methods, the expertise and technology does exist to produce them by combining computer and conventional practices, (i.e. as a case in point the two-variable choropleth maps created by the U.S. Bureau of the Census). The advantages with computer assisted mapping is that it reduces significantly the amount of time and cost associated with map production.

Experimental Map Designs

One challenge of particular interest to the cartographer is to devise, if possible, an optimum design for two-variable choropleth maps. Given the theoretical purpose of bivariate maps, the innovative designs must depict a separate symbolization scheme for each of the two mapped components while concurrently illustrating the correlation between them. With increasing regularity, researchers are examining this topic and have come up with numerous, interesting, and feasible design alternatives. This research continues the trend by examining four symbolization schemes that have not been studied empirically.

Four experimental bivariate choropleth maps entitled "THE INTERRELATIONSHIP OF EDUCATIONAL ATTAINMENT AND PER CAPITA INCOME" were designed and used in conjunction with the questionnaire to test the research objectives (Appendix I, Test Maps). It should be noted that the test maps in Appendix I are photographs of the originals. The photographs reduced the original size of the experimental maps by 43 percent. All four experimental design alternatives were compiled on a common base map of Prince Edward Island that was obtained from the Geographic Information Manipulation and Mapping System (Gimms). Prince Edward Island was chosen because it was a convenient shape to work with, and also provided ample space for the title and legend. As a matter of interest, the map of Prince Edward Island was one of Gimms' illustrative mapping examples that was included in the software package.

The experimental two-variable choropleth map was designed as follows. Forty-three statistical units or areas of fairly uniform size were created to subdivide the island. The total number of statistical units was kept to a minimum for three reasons. Firstly, to determine if interpretation/communication improved especially at the intermediate and superior map reading levels. Secondly, to accomodate the selected patterns. Thirdly, to deal with the factor of time. Since the experiment was conducted during volunteered class time and the questions in the questionnaire required considerable thought, this researcher did not want to increase the complexity of the maps.

The data used to categorize these statistical units were fictitious. In addition to the statistical units, five distinct regions were created. Each of the five regions were arranged to highlight a dominate characteristic of Per Capita Income and Education (Percent High School Graduates):

1) Region 1: Low Income - Medium Education,

2) Region 2: Medium Income - High Education,

3) Region 3: High Income - Very High Education,

4) Region 4: High Income - Medium Education, and

5) Region 5: Low Income - Low Education.

The identical data were portrayed on each of the maps.

The test map variables used in the designing process were hue, value, black pattern and white pattern. By manipulating these variables, the resulting four test map combinations were produced:

1) hue with black pattern,

2) hue with white pattern,

3) value with black pattern, and

4) value with white pattern,

Black or white pattern was consistently used to represent Education while hue or value was always employed to portray Per Capita Income. An important point to recognize is that in order for a map to communicate information accurately and efficiently the symbol-value relationship should be logical, straightforward and easy to understand to the point that the choice of symbolization is almost automatically interpreted by the map reader. The characteristics of pattern, hue, value, and chroma as it relates to the symbol-value relationship in graphic design will be elaborated on.

The rest of the experimental map design subsection will deal with four topics in the following order; a) the selection of two pattern schemes, 2) the selection of two color progressions, 3) the 4x4 matrix legend, and 4) the production of the four experimental maps. The first set of variables to be discussed is black pattern and white pattern. Because pattern has been commonly used as an area symbol, Education was represented by variations in pattern. The fact that there are potentially hundreds of unique pattern combinations available to the cartographer makes the graphic design component pattern complex to work with.

In order to make the complexity more manageable, it helps to further subdivide pattern into the following four graphic elements listed below (Robinson et al., 1984: 187):

(a) Size - describes the magnitude of the marks whether they are, for example, thick or thin, and large or small;

(b) Shape - marks can be represented in numerous ways, for example, circular dots, squares, diamonds, and curved lines to name a few;

(c) Spacing - refers to the distance between the marks; and

(d) Orientation - describes the direction of the marks in relation to the map border and the map user's viewing angle.

The final patterns chosen to represent changes in Education were one of two colors: A) black pattern or B) white pattern. The selected patterns were chosen because they were distinctive, easily identified, and a connotative meaning could be attached to the resulting progression. The order for the black pattern depicting increasing Education (Percent High School Graduates) was as follows:

1) small widely spaced dots,

2) spaced dashed lines,

3) diagonal lines, and

4) thick vertical lines.

As education increased so did the amount of area covered by the black pattern. The end product was a legend that visually ranged from light (low income-low education) to dark (high income-high education) as both income and education increased.

Identical white patterns were used to represent education but it was decided to structure the placement of the white pattern in the manner opposite from that of the black. This decision was adopted based on the perception of the combination of color and white pattern. Perceptually the final legend design ranged from light (low education-low income) to dark (high education-high income) as both education and income increased. The two categories with the largest combination of Per Capita Income and Education would be recognized as the darkest value of green with the least amount of white pattern covering the area. It was hypothesized that subjects would obtain improved results working with the reverse pattern. Figure 3.1 illustrates the test maps symbolization schemes in detail.

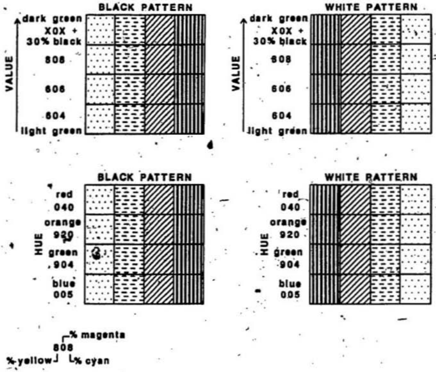


FIGURE 3.1 Test map symbolization schemes.

Since these are bivariate maps, another graphical method was selected to represent Per Capita Income. The graphic variable chosen was color because it has been used frequently as an areal symbol. Color has three dimensions that influence the map readers' perception of the data: 1) hue, 2) value, and 3) chroma (Robinson et al., 1984: 165-166).

1) Hue is the term used to describe the different visible wavelengths

of the electromagnetic spectrum. When something is identified as blue, green, yellow, or red etc., its' hue is being specified. The symbol-value relationship is not straightforward when hue is used to portray a quantitative variable. Hue customarily denotes qualitative data as opposed to quantitative data.

2) Value is a term used to describe the lightness or darkness of any color, i.e. the grey scale where white and black are located at opposite ends with regularly interspaced shades of grey. Hues can also differ in value, i.e. light green to dark green, without changing their hue. Value is an excellent way to portray quantitative data since magnitude variations become readily apparent. For example, if the hue green is selected to represent income, then increasingly darker shades of green denote higher income.

3) Chroma, a term used to describe the intensity of color, is not as significant from a perceptual viewpoint. Only when it is used incorrectly does it become important, i.e. if a selected color is too intense it could dominate the map and create false impressions.

The data for Per Capita Income had a definite order, and consequently the selected color schemes were arranged to reflect this. It is felt by some researchers that if the data distribution has order, this property should be obvious in the graphic design manipulation (Trumbo, 1981: 220; Wainer and Francolini, 1980: 83-84). Per Capita Income was subdivided into four class intervals and symbolization schemes chosen that illustrated the rise of earned income. Since people find color interesting to work with and aesthetically appealing, color was retained for one mapped component. More importantly, since only one variable had color, it was easy to design two schemes showing the magnitude distribution of income perceptually. First a value progression of four distinctive shades of green, sometimes referred to as an ordered arrangement, was selected to represent Per Capita Income. In this particular case the symbol-value relationship was easy to detect and comprehend because as the value of green increased, so did the amount of income.

The second symbolization strategy devised to represent Per Capita Income was based on the color spectrum. Four different hues were selected to show the magnitude of the distribution. According to (Wainer and Francolini, 1980: 83-84) the spectrum is a natural ordering of color but to most people this is not visually apparent. As a result, it is frequently referred to as an unordered arrangement. The four hues selected were blue, green, orange, and red. The percentage of yellow, magenta, cyan, and black used to generate these four colors will be identified later in this chapter. The selected colors were chosen because they were distinctive, their range spanned the color spectrum, and they were basically equal in intensity. Maintaining an equal intensity was required so that no one hue would be more prominent than another. To summarize, the two chosen symbolization schemes highlighted the progression or order of the distribution but this ordering was more visually compelling in the first scheme than the second.

In the experiment both hue and value were used to compare their effectiveness in the map perception process. It was hypothesized that selecting either four different hues, sometimes referred to as an unordered arrangement, or a value progression of one hue, an ordered arrangement, to represent Per Capita Income would make no difference in the number of correct responses.

The consensus for univariate mapping is for the symbolization scheme to reflect the magnitude of the distribution. Some say that a symbolization scheme blatantly showing the magnitude of the distribution is necessary, while others say and imply (Mersey, 1980: 125; Eyton, 1984) that bivariate mapping is more complex and possibly previous cartographical theoretical practices may have to be modified. At this particular point, it is very important to analyze the role of the legend in two-variable choropleth mapping.

The legend plays a major role in the map interpretation/communication process because it is the key to unravelling the information portrayed on the map. It is especially important to recognize this point as statistical maps are becoming increasingly complex - (i.e. the two-variable choropleth mapping method being just one example). One factor responsible for the increase in complexity is the accessibility of statistical, graphic design, and computer approaches. As Olson

(1981: 275) indicated, the legend should be prominently placed on the map and at a size large enough so that the information can be explained as succinctly as possible. It is vital that the legend is legible since this is where the map interpretation/communication process begins.

The design of the legend as well as the classification of the data will be addressed next. In this particular case, the legend created for the experimental maps was a 4x4 matrix legend that had a total of 16 statistical units or cells. Both Per Capita Income and Education (Percent High School Graduates) were represented by four class intervals each. The classification scheme for Per Capita Income was as follows:

1) LOW -- under $8,000,

2) MEDIUM -- $8,000-14,999,

3) HIGH -- $15,000-19,999, and

4) VERY HIGH -- $20,000 or more.

Additionally, Education was represented by the following class intervals:

1) LOW -- 0.0-34.9,

2) MEDIUM -- 35.0-64.9,

3) HIGH -- 65.0-84,9, and

4) VERY HIGH -- 85.0 or more.

The words qualifying the intervals for both Per Capita Income and Education - LOW, MEDIUM, HIGH, AND VERY HIGH - were necessary to include in the legend to emphasize the class interval's place in the hierarchy and to remove any ambiguity when the terms were used in the questionnaire (Figure 3.2).

As articulated previously Per Capita Income was represented by variations in color, and Education by different patterns. One very considerable advantage was that it was easy to separate the two distributions, (i.e. income was shown by four rows of color and education was shown by four columns of pattern), and

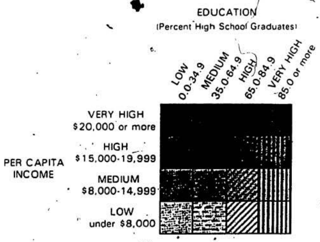


FIGURE 3.2 Experimental legend design.

their combination did not result in one variable obscuring the other. In order to facilitate the discovery of extreme data combinations for further analysis, the four corners of the legend were designed to be very distinctive. Along the two major axes illustrating the positive correlation, from lower left corner to upper right, and the negative correlation, form upper left to lower right, clearly demonstrates a good progression.

The four color test maps were created, by the author, using the facilities of the Memorial University of Newfoundland Cartographic Laboratory (MUNCL). A total of 24 color maps were produced, (i.e. more specifically six maps of each of the four symbolization schemes). The base map obtained from Gimms was printed on the Nicolett-Zeta plotter, and subsequently reduced to the required size. Once the dimensions of the map were established, the coastline, statistical units or areas, regions, and neatlines were scribed. Peelcoats were generated from these scribecoats, and then the four corresponding composite negatives, one for each color, (i.e. cyan, magenta, yellow and black), were created. The test maps were duplicated using Transfer-Key, the 3M Brand MR 434 Processor, and

Lameninator. This processing method ensured color fidelity and consistency for the 24 color test maps. As a preventative measure to keep the experimental maps free of unwanted marks from students' pens and pencils, the maps were encapsulated with clear mylar.

Experimental Questionnaire

The questionnaire was composed of an introduction and four separate parts for a total of 32 questions (Appendix I, Experimental Questionnaire). The first two pages of the questionnaire booklet contained an introduction to the experiment and bivariate choroplethic mapping, in addition to personal data questions. For example, subjects were asked to state; 1) if they were colorblind, 2a) their age, 2b) sex, 3a) major field of study, 3b) year(s) of university, 4) number of courses completed in cartography, and 5) if they had worked with maps similar to these previously. People who were colorblind were not tested. It was stressed that the mapping method was being tested and not their ability to answer map reading tasks. If subjects were unable to answer any question, they were encouraged not to guess. Instead, it was suggested strongly that they leave the response blank, and proceed to the next question.

As mentioned previously the questionnaire consisted of four parts. Each part was designed with a specific purpose in mind that will be elaborated starting with the next paragraph. There were 32 questions in total and the breakdown by level of map reading was as follows:

A) two questions at the elementary level,

B) twenty-four questions at the intermediate level, and

C) six questions at the superior level.

The questionnaire was constructed to include the majority of the questions at the intermediate and superior map reading levels since these were the levels at which two-variable choropleth maps were designed to excel. Given that questions asked at the superior map reading level were inherently difficult, a concerted effort was made to insure that the questionnaire was not so demanding that students could not complete it in one 50 minute class period. This was accomplished by varying the degree of difficulty basically in the intermediate level questions.

The principal aim of Part 1 was to examine the subjects' ability to answer map reading questions considering both variables, Per Capita Income and Education (Percent High School Graduates). The first question dealt with specific categories of both distributions at the elementary reading level allowing participants to answer a relatively easy question and become familiar with the map. The next seven questions of Part 1 were at the intermediate map reading level, while the last question was at the superior map reading level.

Part 2 consisted of ten questions at the intermediate level of map reading. Each question dealt with only one mapped variable in order to ascertain how proficiently the participants could separate the two distributions and extract the necessary information.

Part 3 consisted of four questions at the superior level of map reading. Here the subjects were required to examine the correlation between the two distributions.

Part 4 contained nine questions, and was designed much like Part 1. The first question was at the elementary reading level. The next two at the intermediate reading level, followed by one question at the superior map reading level. The remaining five questions were at the intermediate level of map reading.

Parts 1 and 4 were switched, with regards to their order of presentation, so that half of the participants completed Part 1 first and the other half Part 4. Subjects were not aware of this occurrence since pagination was altered in the respective experimental packages. A comparison of the results was made between the two groups to determine if after answering all the previous questions, the subjects' performance improved in the last section. Switching or reversing the order of presentation between Parts 1 and 4 was the method used to examine learning effects. The design of the experimental questionnaire was modelled after Mersey (1980).

Methodology

SUBJECTS. The sample group for this experiment was 120 university students. Four test groups consisting of 30 subjects each examined one of the four alternate map designs. University students were selected because they were accessible and most likely to utilize these maps sometime during their study and related work. Subjects with varying years of university and taking courses in Geography and Earth Sciences, were randomly selected to participate. Participation was strictly voluntary as no money was offered.

EXPERIMENTAL DESIGN. The experiment consisted of four experimental maps and a task-specific questionnaire. The participants worked with only a single design alternative in order to eliminate any bias towards another design by increased learning effects. Consequently this research was a between-subjects design.

Nine groups of subjects were tested and the number in each sitting varied depending on the number of students in the class. All testing took place in a classroom, although not the identical classroom. Each classroom had adequate seating, placement, and lighting. Eight of the nine groups were actual classes the professors graciously allowed me to utilize. The ninth group was an ad hoc group of university students who were necessary to obtain the required number of subjects.

Six of the nine groups were Geography classes, two were Earth Sciences classes and the remaining one was the ad hoc collection of university students. Although it appears that all the subjects were solely in Geography or Earth Sciences, examining the composition of the subjects further by their declared major(s) suggests otherwise (Table 3.1).

All experimental design alternatives were compiled on the identical base

TABLE 3.1 Total of participants by declared major(s).

DECLARED MAJOR(S)	NUMBER OF STUDENTS
Geography	44
Earth Sciences	34
Education	8
Physical Education	7
Undeclared Major	5
Education/Geography	3
History/Geography	3
Computer Science/Geography	2
English	2
Anthropology	1
Geography/Forestry College	1
Geophysics	1
History	1
Education/Geography/History	1
Political Science	1
Education/History	1
Business	1
Mathematics	1
Biology	1
French	1
Computer Science	1
	TOTAL 120 STUDENTS

map of Prince Edward Island. The base map was divided into five regions and contained a total of 43 statistical units. The questionnaire was composed of four distinct parts and had a total of 32 questions. The questions were identical but their order of presentation varied. All four parts of the questionnaire had a specific time limit that previously had been determined in a pre-test.

The length of the time limit was resolved in a pre-test in which three university students participated. Although only a minimum amount of data were collected in the pre-test, it was analyzed to ascertain if there were any problems with the questions and expected results. The results from these three subjects were not included in the final statistical analysis. The following time limits were imposed during the experiment:

a) Introduction - 5 minutes,

b) Part 1 - 11 minutes,

c) Part 2 - 5 minutes,

d) Part 3 - 5 minutes, and

e) Part 4 - 11 minutes.

In total, the test took 40 minutes to complete including the verbal instructions. All subjects were treated equally. Names were not recorded and it was stressed that the mapping method was being tested and not their ability to answer map reading tasks.

PROCEDURE. The experiment consisted of identical booklets containing an introduction to bivariate mapping, a questionnaire and one of four test maps. The test maps were randomly distributed to the subjects, i.e. in a classroom all four alternate designs and the two possible questionnaire arrangements were distributed to control the possible copying of answers from one subject to another. Students were informed that the four test maps and two questionnaires were distributed randomly, thus the chances of their neighbour having the identical experimental package was minimal. The maps were randomized considering the eight variables (Table 3.2). The eight variables were given a unique label number. Next a table of random numbers was consulted to determine the order in which the maps and the questionnaires should be presented to ensure randomness.

TABLE 3.2 Eight graphic design combinations that were presented randomly.

PER CAPITA INCOME (COLOR VARIATION) (Map Design)	EDUCATION (PATTERN VARIATION) (Map Design)	ORDER OF PRESENTATION (PART 1 OR PART 4 FIRST) (Questionnaire Design)	LABEL NUMBER
Green (value)	Black	Part 1	1
Green (value)	Black	Part 4	2
Green (value)	White	Part 1	3
Green (value)	White	Part 4	4
Hue (multi-color)	Black	Part 1	5
Hue (multi-color)	Black	Part 4	6
Hue (multi-color)	White	Part 1	7
Hue (multi-Color)	White	Part 4	8

Finally, a list of instructions was read to every group prior to commencing the experiment.

"For my master's thesis I'm studying a 'two-variable' map design. I require students to participate by answering questions using these maps that I have designed and produced. No names will be recorded. Each of you will receive one map and one questionnaire booklet. Each of the maps and the questionnaires are slightly different.

The questionnaire booklet contains an introduction and four different parts. There will be a time limit to answer each Part and I will tell you what that is before you start. Please wait for instructions when to start and stop each section.

Since these maps are in color, when I pass them out, tell me if you are colorblind. If you are, you will not be required to participate. Do not open the folders until instructed. If at any time you have any questions, ask. Do not leave until the time is finished.

Thank-you!"

After the instructions were read to the group, the experiment commenced. Subjects were issued explicit instructions when to start and stop each section. Participants were not permitted to study the other questions if they had completed a particular section before the time limit. Further enquiries concerning the overall objectives of the study were answered, if necessary, after each group had completed their respective experiment. The data for this study were collected from the questionnaires and then further analyzed.

CHAPTER 4

ANALYSIS AND RESULTS

Previous studies have shown that two-variable choroplethic mapping is flexible graphically to the cartographer and certainly a viable technique in terms of map user comprehension. The majority of the bivariate choropleth map designs proposed and the ones ultimately tested were concerned with the employment of color to represent mapped components. For example, Olson (1981), Wainer and Francolini (1980), and Mersey (1980) Experiment I, examined, the readability of spectrally-encoded two-variable maps produced by the U.S. Bureau of the Census. Of the six designs tested by Mersey (1980) Experiment II, four consisted of a color scheme for each of the two spatial variables and the remaining two symbolization schemes were composed of a combination of color and black pattern. Carstensen's (1982) approach was completely different. He used line spacings to generate patterns and no color for one of his experiments. The present study incorporated both color variation to represent one variable and pattern variation to represent the second variable. Color and pattern variations were selected as a combination for the following reasons. Graphically the two separate distributions are distinctive, thereby permitting the map user to determine if a correlation between the two variables exists. To the cartographer these maps offer increased graphic design flexibility in that more experimentally tested and proven effective map designs could be utilized confidently to represent data.

The main objective of the present research was to investigate quantitatively the full potential of the two-variable choroplethic mapping method by focusing on the efficacy of the four alternate map designs produced for this study. In more specific terms full potential means the extent to which the experimental maps fulfill their main purpose of portraying two geographic distributions and their correlation, thus indicating their readability to the map user. Statistical methods were employed to analyze the empirical data collected from the experiment. The results from these analytical techniques played a major role in substantiating research hypotheses and conclusions.

The experiment was designed to measure how successfully map users could extract information by asking subjects to answer the questionnaire while examining one of the four alternate test designs. The analysis was based on the correct number of responses obtained from the questionnaire. The marking scheme was straightforward. There were 32 questions in total, and one mark was assigned for every correct response yielding a possible perfect score of 32.0.

Selection of Statistical Tests

Several statistical tests were employed to determine if any significant differences in accuracy occurred between the four alternate symbolization schemes. As a preliminary analytical step, a graph depicting the total correct score of all four experimental designs combined was drawn to determine the distribution of data from which further statistical tests would be influenced (Figure 4.1). This graph depicts the Total Number of Correct Responses versus the Total Number of Subjects who obtained that score. In examining Figure 4.1, it was obvious that the data distribution was not normal but negatively skewed. Since parametric tests are based on the assumption of a normal population distribution, non-parametric statistical tests were used mainly for the analysis. Non-parametric statistical tests, generally referred to as distribution free, do not require the normal population assumption.

Order of Presentation

Because the experimental questionnaire was constructed to test various premises or hypotheses, it was necessary to ascertain if the design factor affected or biased the overall results. The specific case where this applies was the ordering method used to measure learning effects. To measure learning effects half the subjects received Part 1 first and the remaining half, Part 4. Parts 2 and 3 were always presented in the identical sequence, i.e. Part 2 followed by Part 3. A Mann-Whitney U Test (Silk, 1979: 185-191) was used to determine if the questionnaire design influenced the number of correct responses overall. It is assumed that the ordinal data were obtained from random sampling. Table 4.1 illustrates the statistical results related to the order of presentation. At the 95%

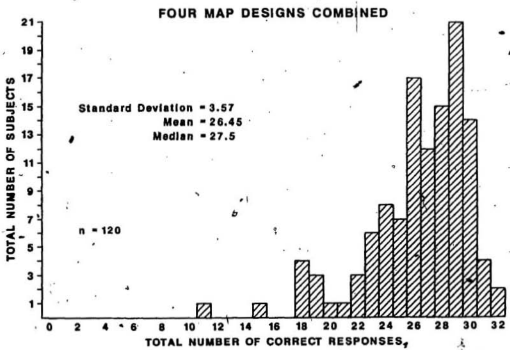


FIGURE 4.1 Graph showing the total correct scores obtained by the four experimental map designs.

TABLE 4.1 Order of presentation.

ORDER 1 – Subjects completed the experimental questionnaire by the following sequence - Part 1, Part 2, Part 3, and Part 4.

ORDER 2 – Subjects completed the experimental questionnaire by the following sequence - Part 4, Part 2, Part 3, and Part 1.

MEAN RANK	CASES	ORDER	CONFIDENCE LEVEL ATTAINED
65.68	60	1	89.98%
55.32	60	2	

confidence level the null hypothesis stating that the questionnaire design did not influence the number of correct responses overall was accepted. The implication of this result is overall the questionnaire design was one factor that did not require further consideration when applying subsequent statistical tests.

Black Pattern and White Pattern

Two unique symbolization schemes were selected for each variable, Education and Per Capita Income, to determine if any one of the designs optimized map utility or performance. Education (Percent High School Graduates) was represented by either black pattern or white pattern. Half of the sample worked with black patterned maps while the other half worked with white patterned maps. It was hypothesized that subjects using the white patterned maps would obtain better results because the literature indicated that white patterns perceptually appear larger to the map reader and therefore were easier to distinguish (Greenberg, 1968: 138). A Mann-Whitney U Test was used to ascertain if there was a significant difference in performance between black and white patterned maps. Table 4.2 shows the statistical results. At the 95% confidence level there was no difference between the two patterns, the null hypothesis was accepted. This means that subjects were equally divided in their performance. The outcome was contrary to what was expected or hypothesized. There are two possible reasons why this result occurred. Firstly, perhaps people are more adept at dealing or working with black pattern as opposed to white pattern. Secondly, the black pattern demonstrates more clearly the magnitude

TABLE 4.2 The results of the Mann-Whitney U Test used to determine if there was a significant difference between black and white patterned maps.

MEAN RANK	CASES	PATTERN GROUP	CONFIDENCE LEVEL ATTAINED
65.78	60	Black Pattern	90.61%
55.22	60	White Pattern	

progression to the data, i.e. as Education increases so does the amount of black pattern covering the area. Conversely, the white pattern was organized to ensure that the highest class interval of Per Capita Income and Education contained the most amount of color.

Hue and Value

Per Capita Income, the second variable mapped, was symbolized with either an ordered or unordered color arrangement. Once again, half the sample worked with green maps while the remaining half worked with the four spectrally colored maps. The objective was to determine if there was a significant difference between the ordered and unordered color arrangements regarding the number of correct responses obtained from the questionnaire while utilizing these maps. A Mann-Whitney U Test was the statistical test used. Table 4.3 shows the statistical results.

TABLE 4.3 The results from the Mann-Whitney U Test concerning the difference between an ordered and unordered color arrangement.

MEAN RANK	CASES	MAP COLOR GROUP	CONFIDENCE LEVEL ATTAINED
58.30	60	Green	51.46%
62.70	60	Color	

The null hypothesis stated that there would be no significant difference in performance between the two groups at the 95% confidence level, and it was accepted. This result was consistent with previous experiments dealing with color symbolization schemes (Mersey, 1980).

Levels of Map Reading

A more detailed analysis of the data was required to make further comprehensive conclusions. Since the questionnaire was designed to incorporate Bertin's three levels of map reading, the results were examined by this factor in order to specifically determine which alternate design(s) facilitated certain map reading tasks. In total there were 32 questions and the breakdown by map reading level is detailed in Table 4.4.

TABLE 4.4 Breakdown of the experimental question by map reading level.

ELEMENTARY LEVEL	INTERMEDIATE LEVEL	SUPERIOR LEVEL
Part 1-Question 1	Part 1-Question 2(a)	Part 1-Question 4
Part 4-Question 1	Question 2(b)	Part 3-Question 1
	Question 2(c)	Question 2
	Question 2(d)	Question 3
	Question 2(e)	Question 4
	Question 3(a)	Part 4-Question 3
	Question 3(b)	
	Part 2-Question 1, Regions 1-5)	
	Question 2, (Regions 1-5)	
	Part 4-Question 2(a)	
	Question 2(b)	
	Question 4(a)	
	Question 4(b)	
	Question 4(c)	
	Question 4(d)	
	Question 4(e)	
Subtotal 2	Subtotal 24	Subtotal 6
		TOTAL 32 questions

Crosstables were used along with a calculated chi-square value to examine if there was a significant difference in performance between subjects using the four design combinations at the three map reading levels. The elementary map reading level was the first one to be analyzed, and there were only two questions. Table 4.5 shows the results of the statistics. As anticipated, there was no difference at the 95% confidence level among the results from the four design combinations

TABLE 4.5 Results of the statistical test studying the map designs at the elementary map reading level.

	GREEN-BLACK GROUP	GREEN-WHITE GROUP	COLOR-BLACK GROUP	COLOR-WHITE GROUP
Number of subjects who answered neither question correctly	0	1	1	0
Number of subjects who answered one question correctly	2	3	2	4
Number of subjects who answered two questions correctly	28	26	27	26

CHI-SQUARE	DEGREES OF FREEDOM	CONFIDENCE LEVEL ATTAINED
3.10280	6	20.42%

since the questions were easy. Thus, the null hypothesis was accepted that subjects performed equally well with any one of the four experimental designs.

The intermediate map reading level was the second level to be studied. Moreover, it contained the greatest number of questions, a total of twenty-four. The 24 questions were further subdivided into two distinct classifications with separate objectives. Group I consisted of all intermediate level questions minus the 10 questions in Part 2. Continuing along, the questions in Part 2 comprised Group II. In Group I the questions asked dealt with both distributions simultaneously. While in Group II, the questions were designed specifically so that participants only had to work with one variable at a time. Additionally, the function of Group II was to determine if there was a difference in how successfull subjects were at extracting single distribution information from a bivariate map. The statistical results from Group I will be discussed first.

The data were examined to ascertain if there was a significant difference among the four experimental designs in performance at the 95% confidence level.

The null hypothesis stated that there was no difference between the four map designs at this level, and at this stage it was accepted. Next, the data were placed into three categories: (1) subjects who answered only one to eight of the intermediate level questions correctly, (2) students who answered nine to eleven of the intermediate level questions correctly, and (3) subjects who correctly completed twelve or more questions. Table 4.6 shows the statistical results.

TABLE 4.6 The results of the statistical test studying the map designs at the intermediate map reading level, Group I.

	GREEN-BLACK GROUP	GREEN-WHITE GROUP	COLOR-BLACK GROUP	COLOR-WHITE GROUP
Number of subjects who answered a minimum of eight questions correctly	3	3	6	4
Number of subjects who answered nine to eleven questions correctly	6	17	7	10
Number of subjects who answered twelve or more questions correctly	21	10	17	16

CHI-SQUARE	DEGREES OF FREEDOM	CONFIDENCE LEVEL ATTAINED
12.775500	6	95.32%

The null hypothesis was rejected at the 95% confidence level. The order of best map design as judged by the number of correct responses was:

1) green with black pattern,

2) tied in the number of points obtained was color with black pattern and color with white pattern, and

3) last was green with white pattern.

The statistical results from Group II were examined next. As indicated in

TABLE 4.7 Percent number of correct responses for Group II by map design.

	PERCENT NUMBER OF CORRECT RESPONSES FOR PART 2
1. Green with Black Pattern	95%
2. Green with White Pattern	90%
3. Color with Black Pattern	93%
4. Color with White Pattern	90%

Table 4.7, subjects were very successful in separating the two single distributions on the two-variable choropleth map design. This confirmation is of significant importance since being able to deal effectively with the two separate geographic distributions is one of the premises of two-variable choropleth mapping. The results of this present study, with regards to the readability of the two single distributions, is comparable to Mersey (1980: 109) Experiment II. The range of test scores obtained from her six experimental designs was between 94% and 99%.

There were six questions at the superior reading level. Firstly, the data were examined on a question by question basis, one through six, to determine if there was a significant difference among the four design combinations. Secondly, the data were divided into two groups: (1) the number of subjects who only answered one to three of the superior level questions correctly and (2) the participants who answered four to six of the superior level questions correctly. Table 4.8 shows the statistical results. After examining the statistical results, the null hypothesis stating there was no difference between map designs for both categories had to be accepted at the 95% confidence level.

The Examination of Learning Effects

Researchers increasingly are becoming aware that people need to be educated graphically in order for them to comprehend often increasingly complex graphics. It frequently has been suggested that graphicy is one skill that is generally not sufficiently developed throughout our educational system as are numeracy, articulacy and literacy (Balchin, 1976). This research incorporated the concept of learning effects in order to judge its impact. Crosstables were used along with a calculated chi-square value to examine if there were any significant

TABLE 4.8 The results of the statistical tests studying the map designs at the superior map reading level.

	GREEN-BLACK GROUP	GREEN-WHITE GROUP	COLOR-BLACK GROUP	COLOR-WHITE GROUP
Number of subjects who answered one to three questions correctly	6	14	9	9
Number of subjects who answered four to six questions correctly	24	16	21	21

CHI-SQUARE	DEGREES OF FREEDOM	CONFIDENCE LEVEL ATTAINED
5.08344	3	83.42%

differences in learning effects between Part 1 and Part 4 only. The number of correct responses from subjects who completed Part 1 first were compared with the number of correct responses from subjects who completed Part 1 last. The identical test was carried out on the results obtained from Part 4. Tables 4.9 and 4.10 show the statistical results.

TABLE 4.9 Statistical results concerning the role of learning effects as it applies to Part 1.

	INCORRECT RESPONSE	CORRECT RESPONSE
Part 1 completed first	37	503
Part 1 completed last	34	506

CHI-SQUARE	DEGREES OF FREEDOM	CONFIDENCE LEVEL ATTAINED
0.13568	1	28.74%

There was no difference in the number of correct responses whether Part 1 was dealt with first or last. The null hypothesis was accepted that participants performed equally when answering Part 1 questions. However, there was a

TABLE 4.10 Statistical results concerning the role of learning effects as it applies to Part 4.

	INCORRECT RESPONSE	CORRECT RESPONSE
Part 4 completed first	199	341
Part 4 completed last	121	419

CHI-SQUARE	DEGREES OF FREEDOM	CONFIDENCE LEVEL ATTAINED
27.01776	1	100.00%

significant difference at the 95% confidence level in the number of correct responses depending on whether Part 4 was completed first or last. When Part 4 was completed last, the number of accurate answers increased dramatically, thereby indicating that as the subjects better understood and became more experienced in working with this map design, their scores improved. It should be noted that even though the questions in both interchanged Parts 1 and 4 were at the identical levels of map reading, the subjects found Part 1 questions easier. Therefore the results from Part 4 give a good indication that learning effects did take place.

The Examination of Each Alternate Design

Each experimental design was examined individually and subsequently cross compared to ascertain which one(s) enabled subjects to extract information most accurately, thus determining the design(s) that evoked a superior performance. Four graphs, one for each of the four symbolization schemes, were drawn (Figure 4.2) showing the Total Number of Subjects versus the Total Number of Correct Responses they obtained. The mean, median, and standard deviation were also listed as additional measures from which comparisons could be made.

The sample size for each of the experimental map designs was 30 university students. For expedient referral Table 4.11 extracts two measures of central tendency and one measure of dispersion from Figure 4.2. Based on the examination of the means, medians, and standard deviations (Table 4.11) the test scores seem good and indicate that subjects were able to use the maps correctly

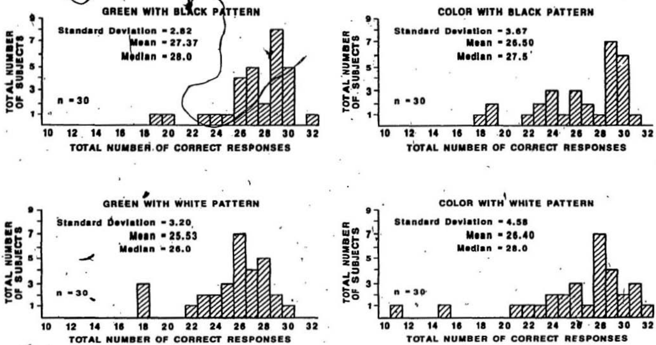


FIGURE 4.2 Graph showing the total correct scores obtained by the subjects for each of the four test map designs.

TABLE 4.11 Two measures of central tendency and one measure of dispersion for each alternate design.

MAP DESIGN	MEAN	MEDIAN	STANDARD DEVIATION
1. Green with Black	27.3667	28.0	2.8221
2. Green with White	25.5333	26.0	3.2027
3. Color with Black	26.5000	27.5	3.6742
4. Color with White	26.4000	28.0	4.5833

when answering the questions, thereby indicating an apparent high level of understanding. Firstly, the largest difference between the mean scores was 1.83, the lowest being 25.53 and the highest 27.36. Out of a possible perfect score of 32.0, these results clearly indicate that the data portrayed (i.e. symbolization schemes) and the mapping method are proficient. Secondly, examining the range of the calculated medians among all four maps only a small difference of 2.0 existed. Thirdly, the lowest standard deviation, 2.82, occurred on the green with black test map, while the color with white test map showed the largest standard deviation of 4.58. The highest standard deviation indicates that the test scores on the color with white test maps varied the greatest.

Examining all graphs, (Figure 4.2), the data once again indicated a skewness to the left or negatively. Since the data distribution was non-normal, the Kruskal-Wallis Analysis of Variance By Ranks (Silk, 1979: 192-195) test was selected twice to compare the experimental map designs. Firstly, the total number of correct responses for each experimental design was calculated and then studied. Secondly, since the questionnaire consisted of four distinct sections, all four parts were analyzed individually by symbolization scheme to investigate further for significant results. The basic assumptions of the Kruskal-Wallis Analysis of Variance are: (a) ordinal data were obtained from random sampling, (b) that a minimum of three populations were being compared, (c) the null hypothesis states that no differences exist between the population distributions and (d) the alternate hypothesis maintains that a minimum of one inequality exists.

The Kruskal-Wallis Test showed that there was no significant difference at the 95% confidence level between the four experimental designs when the total number of correct responses from the questionnaire for each experimental group was studied. Table 4.12 shows the statistical results from the Kruskal-Wallis Analysis of Variance by Ranks.

TABLE 4.12 The statistical results from the Kruskal-Wallis Analysis of Variance by Ranks for each experimental group.

MAP DESIGN	MEAN RANK	CASES	CONFIDENCE LEVEL ATTAINED
1. Green With Black	68.98	30	89.89%
2. Green With White	47.62	30	
3. Color With Black	62.58	30	
4. Color With White	62.82	30	

However, when all four parts were examined individually, only Part 4 showed a significant difference at the 95% confidence level in favor of the ordered arrangement (green) with black pattern. Table 4.13 shows the results of this test. For both the Total By Group and Parts 1 through 4 By Group, the order of best performance by map design was:

1) green with black pattern.

2) color with white pattern

3) color with black pattern, and

4) green with white pattern.

These results support the previous studies particularly by Olson (1981), Mersey (1980), and Carstensen (1981). Olson's (1981) research gave the first indication that subjects were not reluctant to work with two-variable maps. When explanatory notes were attached, participants started to become more proficient in utilizing and understanding the mapping technique. Mersey's (1980) research compared the accuracy results among six experimental map designs, but no one design was judged to be superior overall. Generally, subjects answered the questions in the experimental questionnaire with acceptable results. Carstensen

TABLE 4.13 The statistical results from the Kruskal-Wallis Analysis of Variance by Ranks by part for each map design.

PART 1

MAP DESIGN	MEAN RANK	CASES	CONFIDENCE LEVEL ATTAINED
1. Green with Black	57.93	30	17.12%
2. Green with White	58.05	30	
3. Color with Black	63.12	30	
4. Color with White	62.90	30	

PART 2

MAP DESIGN	MEAN RANK	CASES	CONFIDENCE LEVEL ATTAINED
1. Green With Black	66.47	30	72.24%
2. Green With White	52.40	30	
3. Color With Black	64.28	30	
4. Color With White	58.85	30	

PART 3

MAP DESIGN	MEAN RANK	CASES	CONFIDENCE LEVEL ATTAINED
1. Green with Black	54.93	30	84.51%
2. Green with White	53.57	30	
3. Color with Black	63.38	30	
4. Color with White	70.12	30	

PART 4

MAP DESIGN	MEAN RANK	CASES	CONFIDENCE LEVEL ATTAINED
1. Green with Black	73.65	30	95.54%
2. Green with White	48.68	30	
3. Color with Black	58.82	30	
4. Color with White	60.85	30	

(1981) used the crossed-line, continuous-tone shading method and determined that once the mapping method became familiar and was understood by the students, it could be applied successfully. All three studies, in addition to this research, indicate that bivariate mapping is a viable technique with numerous graphic design possibilities and considerable flexibility. The main criterion is that students have to be able to comprehend the mapping technique.

Formal Education

Earlier studies (Mersey, 1980; Olson, 1981; Carstensen, 1981) have given a good indication that the more experienced map reader will obtain the best scores. Experience, in this current research, was measured in three ways based on personal information obtained at the beginning of the questionnaire. The questionnaire required subjects to indicate: (1) their year of university study, (2) the number of cartography courses completed to date and (3) if they previously had used two-variable choropleth maps.

The number of years subjects were in university ranged from one to eight. Two groups were created. The first group was designated inexperienced and it consisted of subjects who were in their first to their third year of university. The second group, designated experienced, were students who were in their fourth year through to graduate studies. It was felt that the experienced group would perform the best since they would have completed more university courses. A Mann-Whitney U Test was used to determine if there was a significant difference in performance between the two groups. Table 4.14 shows the statistical results.

TABLE 4.14 The outcome of the Mann-Whitney U Test used to determine if there was a significant difference in years of university education.

MEAN RANK	CASES	EXPERIENCE CLASSIFICATION	CONFIDENCE LEVEL ATTAINED
53.03	63	Inexperienced	98.72%
68.75	57	Experienced	

At the 95% confidence level the experienced group performed statistically better.

The number of cartography courses taken ranged from zero to ten. Two groups were again created. The inexperienced group consisted of students who had not completed any cartography courses. The experienced group consisted of participants who had completed one or more cartography courses. Students in the latter group had a greater chance of being introduced to this type of mapping. A Mann-Whitney U Test was applied to determine if there was a statistical difference between the inexperienced and experienced subjects. Table 4.15 below shows the statistical results.

TABLE 4.15 Results from the Mann-Whitney U Test used to determine if subjects with courses in cartography worked significantly better.

MEAN RANK	CASES	EXPERIENCE CLASSIFICATION	CONFIDENCE LEVEL ATTAINED
58.45	92	Inexperienced	76.11%
67.23	28	Experienced	

The test results showed that there was no significant difference in performance between the two groups at the 95% confidence level. It should be noted that approximately one-fourth of the sample was classified as experienced, while three-fourths were categorized as inexperienced. Significant results are often difficult to obtain when the difference between the two samples being compared is so large.

The third and last indicator used to examine map reading experience was previous practice with two-variable choropleth maps. Once again two groups were created. The inexperienced group consisted of subjects who stated they had not used this type of map previously. The experienced group was comprised of participants who indicated they had used two-variable choropleth maps prior to this experiement. A Mann-Whitney U Test at the 95% confidence level determined there was no significant difference between the two classifications. Table 4.16 shows the statistical results.

TABLE 4.16 Results obtained from the Mann-Whitney U Test used to determine if prior experience with two-variable choropleth maps made a significant difference.

MEAN RANK	CASES	EXPERIENCE CLASSIFICATION	CONFIDENCE LEVEL ATTAINED
59.78	37	Experienced	12.05%
60.82	83	Inexperienced	

Although approximately one-third of the subjects stated they had used these maps previously, the results seem to suggest that they may not have had a good or solid understanding of the mapping method.

Having reviewed the three indicators that were used to measure the effect of experience on the map interpretation/communication process, the first classification studied (i.e. number of years in university) was the strongest indicator. It appears that students with more years of university have learned to apply themselves to challenging situations or circumstances. In addition the two groups, inexperienced - containing 63 students - and experienced - containing 57 students, were more equal in size facilitating a reliable comparison. The other two indicators, i.e. number of cartography courses completed and previous bivariate mapping experience, had a more pronounced size difference as discussed previously. Appendix II gives a complete record of the SPSS/X commands and subsequent statistical results.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

The statistical tests applied to the data collected from the experiment support and strengthen the argument that two-variable choropleth mapping is a favorable technique in terms of cartographic flexibility for the cartographer and map user utility. It is important to have cartographic flexibility because of the numerous graphic options available to the cartographer (i.e. map designs resulting primarily from the accessibility of computer graphics and statistical packages). The success of the mapping method naturally implies established map user utility since, ultimately the map users are the ones responsible for deciding if relevant information can be extracted from the map. The ensuing discussion will link the experimental results from this study with previous analytical findings and speculations, thus, hopefully more firmly establishing and perhaps augmenting current cartographic theory and insight.

Despite the complexity of the map design methods, very positive results were obtained from the experiment concerning the utility of the four alternate designs, and in general, the bivariate mapping method. In subsequent paragraphs these results will be discussed in conjunction with the degree to which the study's objectives were satisfied. The reader should remember that the experimental designs for this thesis consisted of 43 relatively large statistical units, and was based on a 4x4 matrix legend design.

Comparing results obtained from subjects using the black pattern versus the those working with white pattern, there was no significant difference at the 95% confidence level. It should be emphasized that all four alternate test maps were designed to hold constant the conventional perceptual progression. This means that as income and education increased, a corresponding visual progression from light (low income-low education) to dark (high income-high education) was generated. In order to achieve the conventional perceptual progression, it was necessary to reverse the white symbology. Whereas the black pattern increased in area, the white pattern decreased. This was the only possible graphic design approach given the perceptual nature of white symbology on a colored background.

In addition, it was thought that since white patterns perceptually appear larger, subjects would notice the patterns and retain the specific values they represent with greater accuracy. As it turned out, this was not the case. Perhaps black patterns were more familiar to map users, and consequently they felt more at ease working with them. On the other hand subjects may have been confused with the reverse ordering of the white pattern which was done to enable the top statistical cell to be perceived as the darkest, therefore the greatest combined value. Possibly if the white pattern had been the same as the black in sequence, there would have been a significant difference at the 95% confidence level since a statistical difference at the 90% level did occur.

Examining the results of this study, with particular reference to maps with an ordered versus an unordered progression of colors, there was no significant difference in performance with each of these map designs at the 95% confidence level. The statistical outcome was expected because subjects only had to remember four very perceptually separate and distinctive values or hues. This result was consistent with past experiments dealing with color symbolization schemes (Mersey, 1980; Olson, 1981). Mersey's (1980) research - Experiment II, demonstrated that there was no significant difference in performance between conceptual designs pertaining to whether the color scheme was ordered or unordered. As for Olson's (1981) study Experiment 1, spontaneous arrangement of color in a legend, showed that no two subjects created the identical legend. From these results a few observations can be noted. The understanding of color theory seems to be at a relatively low level. In this particular context color theory refers to two specific concepts; (a) an understanding of the visible color spectrum, and (b) which color combinations yield what hue. Perhaps map readers would be successful working with whatever symbolization scheme was chosen by the cartographer as long as some logical connotation could be applied to the design.

Since the bivariate choropleth mapping method was designed to illustrate the spatial distribution of two independent variables, (in this particular case Income and Education), as well as the correlation between them, some method of evaluating the extent to which the design has succeeded was required for further comprehensive conclusions. Thus, another objective was examined. The questions in the experimental questionnaire were designed to incorporate Bertin's (1973) three levels of map reading. Including the theoretical graphic concept of these three map reading levels in this research has a dual purpose. Firstly, it is the continuation of a research trend with this type of mapping (Wainer and Francolini, 1980; Mersey, 1980; Carstensen, 1982) in particular. Secondly, it is in response to an overall need for research to have standard graphic vocabulary which simplifies the expressing of ideas, and therefore enhances communication. By examining the results of each map design at the three levels of reading, perhaps the map design(s) that was better for specific map reading tasks will emerge. The map reading level and the proficiency at which the participants can interpret the portrayed information is a fundamental part of the objective.

The results were examined by the factor level of map reading in order to specifically determine which alternate design(s) facilitated certain map reading tasks. The majority of questions were at the intermediate and superior map reading levels since this is where the two-variable choropleth map was designed to excel.

The elementary map reading level was the first one to be analyzed. Two elementary reading level questions were included at the beginning of the experiment to give the subjects a relatively simple introduction to the questionnaire. As anticipated, there was no difference at the 95% confidence level among the results from the four design combinations since the questions were relatively easy.

However, considering fourteen of the twenty-four questions at the intermediate map reading level or Group I, there was a statistical difference at the 95% confidence level. The order of best performance for experimental map design was:

1) green with black pattern,

2) tied - color with black pattern and color with white pattern, and

3) green with white pattern.

The possible reason why the green and black pattern design excelled over the other designs at this level is that the selected symbolization scheme clearly showed the magnitude distribution for both Income and Education. Additionally, the remaining ten questions at the intermediate map reading level or Group II that required subjects to separate the two single distributions were completed with ease and accuracy. It was obvious that the four conceptual designs were fulfilling one of the premises of the two-variable choropleth map design.

The questions asked at the superior map reading level were the most difficult because subjects had to determine the correlation between the variables at the regional level and over the whole map. Comparing the results there was no significant difference in performance among the participants using the four experimental maps. Table 5.1 shows the correct percent response.

TABLE 5.1 Correct percentage by experimental map design.

MAP DESIGN	No. OF CORRECT RESPONSES / No. OF POSSIBLE CORRECT RESPONSES	CORRECT % RESPONSES
1. Green with Black Pattern	123/180	68.33%
2. Green with White Pattern	108/180	60.00%
3. Color with Black Pattern	122/180	67.77%
4. Color with White Pattern	124/180	68.88%

At the superior level of map reading a minimum of 60% of the answers were correct. This is a good, acceptable result given the facts that these maps were complex and unfamiliar to the majority of the subjects. Mersey (1980: 109) had similar results since the range of correct percent response was from 60%-71%.

The difference between the two experiments was that the six questions in this author's study were based on the map, while in Mersey's (1980) research the subjects only had to use the map for one question. The remaining five questions were based solely on the legend explaining the correlation concept.

Since two-variable choropleth maps are relatively unfamiliar to most subjects and are rather complex to the untutored map user, it is in the interest of the cartographer to ensure that the purpose of the map design and how it functions is explicitly stated. With explanatory text, subjects would be able to use successfully the statistical maps. This is the consensus among researchers who have studied bivariate choropleth maps (Mersey, 1980; Olson, 1981; Wainer and Francolini, 1980; Carstensen, 1980). Common to all four studies was the time taken by the researchers to educate their subjects concerning the intricacies of their respective map designs. In order to obtain meaningful results that reflected the readability of an innovative map design, the purpose of the map design and its application were stated succinctly at the beginning of this author's experimental questionnaire.

A natural extension of educating the subjects as to the function of a two-variable choropleth map, is to examine in detail the role of learning effects in the map interpretation/communication process. The examination of learning effects was one of the objectives. An increase in learning effects clearly shows the subject's ability to use the maps improved as a result of working with them. The experimental questionnaire for this study was designed to measure learning effects. It was confirmed once again that subjects did indeed obtain more correct responses when Part 4 was completed last instead of first. The number of correct responses were fairly equal whether Part 1 was completed first or last. Even though Part 4 consisted of the identical number of questions at the various map reading levels, it took the subject a longer time to answer them. Therefore, these challenging questions were determined to be more sensitive to the study of learning effects. Mersey's (1980) research also examined the positive attributes of learning effects and found that subjects obtained better results when the review section of the questionnaire was completed last rather than first.

As a rule, the map reading tasks given to the students were not easy. These tasks required considerable concentration, comprehension, and learning. The degree of map interpretation difficulty is a reflection of the fact that this innovative design is complex. Nevertheless, the difficult experimental questionnaire did not appear to hinder the subjects from obtaining very adequate scores. These facts are highlighted in the percentage of correct responses in Table 5.2.

TABLE 5.2 Percent correct responses by map design in rank order.

MAP DESIGN	PERCENT CORRECT RESPONSES
1. Green with Black Pattern	91.22%
2. Color with White Pattern	88.33%
3. Color with Black Pattern	87.99%
4. Green with White Pattern	85.11%

The percent correct responses were calculated, for a quick comparison, by converting the mean number of correct responses to a percentage. Of the four map designs, the green and white design had the lowest percent correct responses of 85.11%. Furthermore, this demonstrates that even the lowest score is quite acceptable. Of the two participants who obtained perfect scores of 32.0, one subject worked with the green with black pattern design while the second participant used the color with white pattern experimental map. The objective of the research was to examine the bivariate choropleth mapping method to determine its readability to the map user and graphic design flexibility to the cartographer. Overall, these results prove that the objective was met successfully since the degree to which the university students correctly interpreted the information was very acceptable.

The results substantiate the findings and conclusions from previous comparable studies. For Mersey's (1980: 106) Experiment II, six test maps were designed based on a less complex 3x3 matrix legend but were composed of approximately 100 statistical areas. It was determined that subjects were successful in interpreting the displayed information since the difference in the number of correct responses obtained was minimal. Consequently, the range of the Percent Correct Responses for the six experimental test maps was small, from 75% to 81% (Mersey, 1980: 109). After comparing the statistical outcome from both this present study and Mersey's (1980) research, there was no statistical difference in performance among the respective set of alternate designs. However, the range for the percent correct responses was marginally higher in this present study, 85.11% to 91.22%. Most importantly, all designs were deemed readable and, therefore, successful in fulfilling their purpose.

Carstensen (1982: 68) designed and tested crossed-line, continuous-tone bivariate maps and also achieved successful results. Three complete test maps containing nine statistical units were drawn for experimental examination depicting one of three options: 1) positive correlation, 2) negative correlation, or 3) no correlation. Statistical analysis determined that 86% of the subjects recognized the map with the positive correlation, 83% identified the map displaying the negative correlation, and after viewing the map showing no correlation between the mapped variables, 60% of the sample responded that there was no correlation. Carstensen's (1982) range for percent accurate responses from the maps depicting positive and negative correlation more closely resembled the results obtained in this researcher's experiment. Additionally, the number of statistical units contained on Carstensen's (1982) maps and this author's maps were closer in number. Perhaps there is a correlation between the number of statistical areas and the percentage of correct responses.

Carstensen's (1984) reported experiment determined that there was very little difference in performance between crossed-line, continuous-tone maps and two-variable choropleth maps when subjects were required to create similar and dissimilar contiguous areas. The selected units for each map type closely resembled the other, and overall confirmed that both map designs were successful in communicating information. This second set of test maps were composed of 40 statistical units.

Whatever graphic methods were chosen to represent the data on the two-variable choropleth maps produced by the three cartographers (Mersey, 1980; Carstensen, 1982, 1984; and this present study), no one design could be selected as superior in each individual study. One plausible explanation dealing with the lack of significant difference between alternate map designs has to do with the concept of symbol transparency. The idea was first discussed by (Olson, 1981: 274) when it was noticed that when reading bivariate maps subjects seemed to learn what the symbol combination represented in total and applied this knowledge to the map. Mersey (1980: 124) elaborated on this concept and the analogy used is quite appropriate. Reading bivariate map symbology rather resembles reading words in a sentence. The person ultimately focuses on the meaning of the sentence as opposed to each individual symbol. All the results obtained from Mersey's (1980) six test designs and Carstensen's (1984) reported experiment were very similar, as were the results obtained from this present study. This idea of symbol transparency may explain why all four experimental map designs yielded very similar responses from the participants of my experiment.

Even though two-variable maps were relatively unfamiliar to most tested subjects, they did learn how to use them to obtain the required information. Examination of learning effects provided the indication that only after one rather intensive testing period with these maps, the subjects' graphic skills were constantly improving. As a point of interest, the questionnaire was also designed to ascertain if the experienced person - in terms of number of years in university - was a factor to consider when asking subjects to learn an unfamiliar map design. As it happened, the results from this study, on this matter, coincided with the results that Mersey (1980) obtained. Juniors in her study performed significantly better than freshman. In this author's study, the group designated as experienced, qualified earlier in the paragraph, did obtain results that were significantly greater than inexperienced map users. Carstensen (1982: 60) also noted that results improved as subjects became more experienced, and therefore proficient with the test maps.

The idea of educating the percipient, whether it is in all aspects of map reading or highlighting the purpose of a specific map design, cannot be considered a novel approach. Graphicacy, as articulated by Balchin (1976), is one of four major forms of communication between people. The remaining three are: 2) articulacy, 3) numeracy, and 4) literacy. Balchin (1976: 34) described graphicacy as the "educated counterpart of the visual-spatial aspect of human intelligence and communication". Graphicacy should be recognized as extremely valuable and developed as early as the other three forms of communication. Children's graphic ability occurs early but the curriculum in schools should be planned more consciously to enhance the students natural graphic ability throughout their public education. According to Balchin (1976: 36) since British and North American school systems fail to develop students natural graphic ability, often it is not until they reach university and take courses in areas that depend heavily on graphics that graphic ability is allowed to achieve its full potential. If the early graphic skills were developed as vigorously as the other three forms of communication, there would probably be less difference in performance between the two groups labelled, in this study as experienced and inexperienced in terms of years of university. Thus, all people would be able to work with new map designs on a equal footing, regardless of year of university education.

In summary, the seven objectives were analyzed and the extent of their success was discussed so that they could be incorporated in the overall objective. In essence, the overall objective was a combination of the results obtained from the sections of the experiment that dealt with a specific primary and secondary objectives. Another factor considered was the degree to which the subjects performed overall (i.e. total number of correct responses obtained on the questionnaire). Although no one alternate design could be selected as superior, the experiment clearly demonstrated that two-variable choroplethic mapping is a viable alternative for quantitative mapping. Before such extensive testing there were some researchers who were skeptical about the utility of bivariate maps (Monmonier, 1977; Wainer and Francolini, 1980). But other comments and studies, for example, (Trumbo, 1981; Olson, 1975, 1981; Mersey, 1980; Carstensen, 1982, 1984; Eyton, 1984) and this current research show that it is a very viable technique. This author's study in particular showed that two-variable choropleth maps could be read at all three map reading levels, thus fulfilling the function of the map design at a high level of comprehension.

At the beginning of each new research adventure not all of the issues and situations can be anticipated completely. Hence, comments and especially experimental results are valuable tools to utilize when criticizing one's experiment. The critical assessment of a study naturally elicits suggestions for further improvements. There are a few suggested improvements or enhancements that could be made to this study. On the test maps the boundary lines separating one region from another extended past the landmass of Prince Edward Island. This was done to accentuate the fact that five distinct regions existed on the experimental map. However, while not so much of a problem on the maps with a spectral progression, on the maps with a value progression the region boundary lines on the land mass are not as distinguishable as they perhaps could be.

Not included in the design of the questionnaire, because of the time available to obtain responses from students, were questions devoted to how the university students felt about the mapping method in general, and in particular about the four alternate designs. These thoughts and opinions can prove to be insightful, and perhaps give the researcher ideas about additional changes to further improve cartographic communication. Comments should not be dismissed because they cannot be quantified. Since cartography is both an art and a science intuition, perception, and statistical analyses must be intertwined.

Although not specifically asked for, a few comments concerning the questionnaire and the map designs were given to this researcher. Many subjects felt that the questions in the questionnaire required careful thought and consideration. Some participants stated that the black patterns made the test maps appear darker. Another comment concerned the white patterned maps. It was felt that less of the color progression representing Per Capita Income was visible when white patterns were utilized.

Of all the designs discussed and presented in this thesis, one cannot conclude that a definitive design has been discovered, and consequently assume that there is no reason for future experimentation. Moreover, research conducted to examine a specific problem invariably will produce additional avenues for further study. There are several areas of theoretical cartographic concern that require further investigation. One area of interest is the understanding and application of the role of symbol transparency in interpreting map symbology as it relates to bivariate mapping.

Additional experimentation is necessary in the area of perception of white symbology as an alternative to the more commonly used black symbology. If maps were created with black or white patterns it would be interesting to see the results of an experiment if the color opposite to the selected patterns would be used to distinguish the regional boundaries. Another factor that could be dealt with is the irradiation effect. Due to the irradiation effect, white patterns are perceived as larger than the identical size black colored patterns. It would be interesting to compare maps with black patterns versus maps with white patterns drawn at the perceptual thickness of the black patterns to determine if there is indeed a statistical difference in cartographic communication.

The combinations of patterns that could be used to represent areas on two-variable choropleth maps have by no means been exhausted. Experimentation with different styles of patterns (i.e. patterns distinctly different in terms of size, shape, orientation, spacing, and color) will be challenging.

The number of statistical units contained on a two-variable choropleth map is a factor that requires additional study. It would be interesting to determine if there is a saturation level where literally too much information is portrayed on the map for it to be utilized competently.

Given the numerous graphic choices and production techniques available when designing a two-variable choropleth map, utmost on the cartographer's mind should be both the distribution of the data and what information is to be emphasized (i.e. positive correlation, negative correlation and/or extreme values). These concerns should be kept in mind when further studies of legend and graphic design manipulation are contemplated. It is also possible that these new designs will alter our perceptions and thoughts about how map readers interpret data. At the same time, people's graphic ability will have no option but to increase to the level which will be demanded by the more complex cartographic output. The only way of ensuring the required level of map reading is by educating the map reader.

APPENDIX I

A. Test Map I
B. Test Map II
C. Test Map III
D. Test Map IV
E. Experimental Questionnaire

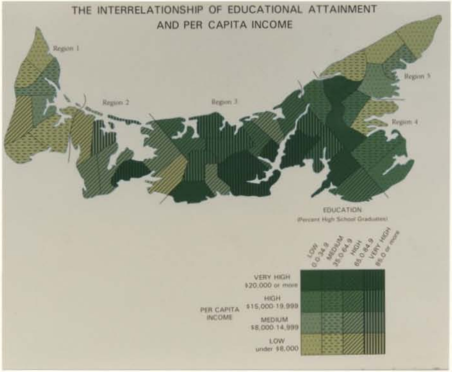


FIGURE I.A Test Map I.

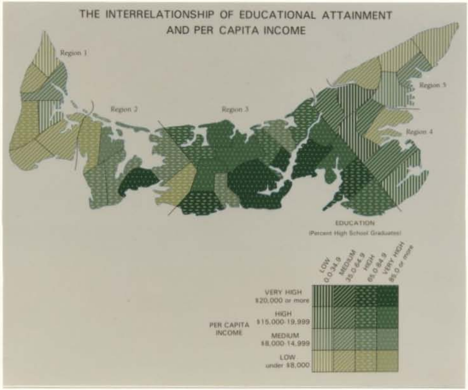


FIGURE I.B Test Map II.

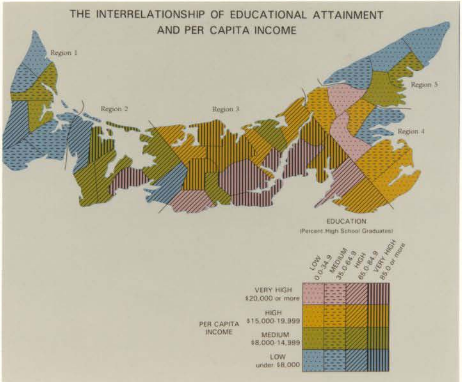


FIGURE I.C Test Map III.

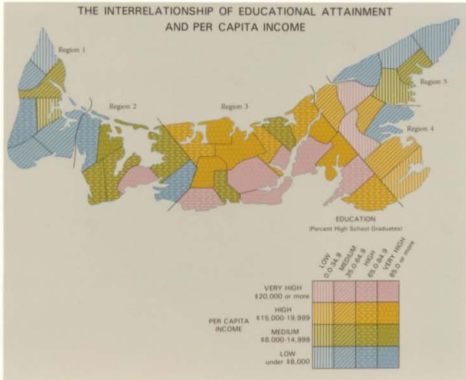


FIGURE I.D Test Map IV.

QUESTIONNAIRE BOOKLET

INTRODUCTION

Before the experiment begins carefully examine the map to familiarize yourself with it. The main objective of this experiment is to study a map design called a "two-variable map". From this two-variable map design, a map reader can distinguish three distributions:

1) the Per Capita Income - (represented by different colors),

2) Education (Percent High School Graduates) - (represented by different patterns) and,

3) the interrelationship between (1) Per Capita Income and (2) Education (Percent High School Graduates) - (represented by the combination of the two patterns - one superimposed on the other).

It is especially important to understand the legend. Both distributions are divided into four categories, each with a corresponding rank; i.e.

PER CAPITA INCOME (represented by different colors)

VERY HIGH
$20,000 or more

HIGH
$15,000-19,999

MEDIUM
$ 8,000-14,999

LOW
under $8,000

continued on the next page ....

EDUCATION (Percent High School Graduates)
(represented by different patterns)

VERY HIGH
85.0 or more

HIGH
65.0-84.9

MEDIUM
35.0-64.9

LOW
0.0-34.9

to create a total of 16 distinct categories.

The purpose of the map is to show how the levels of Per Capita Income and Educational attainment relate to each other over the whole geographical area. Each relatively small area on a map is called a statistical unit. A group of statistical units is called a region. This map has five regions. Generally a region contains statistical units that are relatively similar, e.g. Region 1 with statistical units showing predominantly low income and medium education. It is not uncommon for a region to contain a few statistical units that are not similar, e.g. Region 4 - low income in a region of basically high income and medium education. Once these statistical units are identified, they can be further analyzed to determine the reasons for this disparity.

continued on the next page ....

Remember that this experiment is designed to test a specific mapping method and not the user's map reading ability. If you do not know the answer to a particular question, DO NOT GUESS, leave it blank and proceed to the next question. The experiment consists of four parts, and each part has a specific time limit for you to answer the questions. You will be instructed when to start and stop each section.

Please answer the following questions.

1. Are you colorblind? no ___ yes ___ uncertain ___
2. Age ___ male ___ female ___
3. State your major field of study and year(s) of university.

   major field of study ____________________

   year(s) of university 1 2 3 4 5

   or other ____________________
   specify
4. Number of courses completed in cartography. ____________
5. Have you used these types of maps previously? ____________

Please do not turn the page until instructed to do so.

REMEMBER - DO NOT GUESS - If you do not know the answer to a question, LEAVE IT BLANK!

PART 1.

1. In which region does the combination of Per Capita Income $20,000 or more <u>and</u> Education 85.0 percent or more occur most often.

1 2 3 4 5

2. There are five different regions on the map. Indicate the region, by placing the region number in the space provided, in which the listed combination of variables is found most frequently.

	REGION NUMBER (1 TO 5)
a) Low Income and Low Education	______
b) Medium Income and High Education	______
c) High Income and Very High Education	______
d) Low Income and Medium Education	______
e) High Income and Medium Education	______

3. Identify the one region that fits the criteria listed below by indicating the appropriate region number in the space provided.

   a) One or more statistical units of Very High Income and Very High Education in a region of mostly Medium Income and High Education. ______

   b) One or more statistical units of Low Income and High Education in a region of mostly Low Income and Medium Education. ______

continued on the next page .....

4. Examine Region 5 and select the one statement that best describes the dominant relationship between the variables Education and Per Capita Income.

   ___ Education is generally at a higher level than Per Capita Income.

   _A_ Education is generally at a lower level than Per Capita Income.

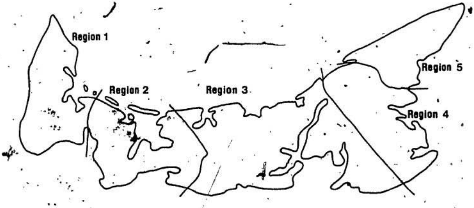
   ___ Education and Per Capita Income are at the same level.

STOP

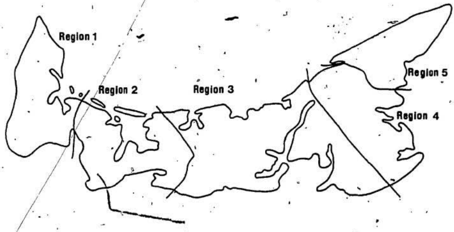
Please do not turn the page until instructed to do so.

PART 2

1. The map below indicates five distinct regions. Label each region with a L (Low), M (Medium), H (High) or VH (Very High) to indicate the appropriate level of Per Capita Income DOMINATING the region.



2. The map below indicates five distinct regions. Label each region with a L (Low), M (Medium), H (High) or VH (Very High) to indicate the appropriate level of Education DOMINATING the region.



STOP

Please do not turn the page until instructed to do so.

PART 3

1. Examine Region 4 and select the <u>one</u> statement that best describes the dominant relationship between the variables Per Capita Income and Education.

   ___ Per Capita Income is generally at a higher level than Education.

   ___ Per Capita Income is generally at a lower level than Education.

   ___ Per Capita Income and Education are generally at the same level.

2. Examine Region 3 and select the <u>one</u> statement that best describes the dominant relationship between the variables Per Capita Income and Education.

   ___ Per Capita Income is generally at a higher level than Education.

   ___ Per Capita Income is generally at a lower level than Education.

   ___ Per Capita Income and Education are generally at the same level.

3. Examine Region 2 and select the <u>one</u> statement that best describes the dominant relationship between the variables Education and Per Capita Income.

   ___ Education is generally at a higher level than Per Capita Income.

   ___ Education is generally at a lower level than Per Capita Income.

   ___ Education and Per Capita Income are generally at the same level.

continued on the next page ....

4. Lastly, examine the total map and select the one statement that best describes the dominant relationship between the variables Per Capita income and Education overall.

   ___ Per Capita Income is generally at a higher level than Education.

   ___ Per Capita Income is generally at a lower leven than Education.

   ___ Per Capita Income and Education are generally at the same level.

STOP

Please do not turn the page until instructed to do so.

PART 4

1. Read the following list of statements and indicate the ONE that best describes the occurrence of statistical units containing Per Capita Income under $8,000 and Education 85.0 percent or more on the map.

___ statistical units containing this particular combination of variables are frequently found throughout the map.

___ statistical units containing this particular combination of variables are concentrated in a small area.

___ statistical units containing this particular combination of variables do not occur on the map.

2. Listed below are four levels of Per Capita Income found on the map. Indicate which ONE occurs most frequently.

___ under $8,000

___ $8,000-14,999

___ $15,000-19,999

___ $20,000 or more

Listed below are four levels of Education found on the map. Indicate the ONE that occurs the least.

___ 0.0-34.9

___ 35.0-64.9

___ 65.0-84.9

___ 85.0 or more

Do not stop, go immediately to the next page ....

3. Examine Region 1 and select the <u>one</u> statement that best describe the dominant relationship between the variables Education and Per Capita Income.

   ___ Education is generally at a lower level than Per Capita Income.

   ___ Education is generally at a higher level than Per Capita Income.

   ___ Education and Per Capita Income are at the same level.

4. Matching problem. Below is a list of regions and a list of characteristics. Examine the specified region(s) and determine what characteristic(s) best describe it. When a single Region is stated, e.g. Region 2, select the answer that best describes the level of <u>both</u> Per Capita Income and Education. If more than one Region is stated, e.g. Regions 1 and 4, select the answer that best describes the <u>one</u> variable they have in common.

REGIONS	CHARACTERISTICS
___ Regions 1 and 5	A) High Income and Medium Education
	B) Medium Income and High Education
___ Region 2	C) High Income
	D) High Education
___ Region 3	E) Low Income
	F) Low Education
___ Regions 1 and 4	G) High Income and Very High Education
	H) Low Income and Medium Education
___ Regions 3 and 4	I) Medium Education
	J) Medium Income

END

Thank-you for your cooperation.

APPENDIX II

A. Statistical Results

1. ORDER OF PRESENTATION

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48  P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1) GROUP=1
IF (COLOR=1 AND PATTERNS=2) GROUP=2
IF (COLOR=2 AND PATTERNS=1) GROUP=3
IF (COLOR=2 AND PATTERNS=2) GROUP=4
RECODE GROUP(1,2=1) (3,4=2)  INTO CGRP
RECODE GROUP(1,3=1) (2,4=2)  INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN  (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL  (4)COLOR-WH/
COUNT PART1=P1SCORE1 TO P1SCORE9(1)
COUNT PART2=P2SCOR1 TO P2SCOR10(1)
COUNT PART3=P3SCORE1 TO P3SCORE4(1)
COUNT PART4=P4SCORE1 TO P4SCORE9(1)
COMPUTE TOTAL=PART1+PART2+PART3+PART4
NPAR TESTS M-W=TOTAL BY ORDER (1,2)

0- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST
     TOTAL
  BY ORDER     ORDER OF PRESENTATION

       MEAN RANK     CASES

          65.68        60   ORDER = 1
          55.32        60   ORDER = 2
                      ---
                      120   TOTAL
                                          CORRECTED FOR TIES
            U              W               Z       2-TAILED P
         1489.0         3941.0         -1.6436       0.1002
```

2. KRUSKAL-WALLIS ANALYSIS OF VARIANCE BY RANKS FOR EACH EXPERIMENTAL GROUP

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1) (3,4=2) INTO CGRP
RECODE GROUP(1,3=1) (2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT PART1=P1SCORE1 TO P1SCORE9(1)
COUNT PART2=P2SCOR1 TO P2SCOR10(1)
COUNT PART3=P3SCORE1 TO P3SCORE4(1)
COUNT PART4=P4SCORE1 TO P4SCORE9(1)
COMPUTE TOTAL=PART1+PART2+PART3+PART4
NPAR TESTS K-W=TOTAL BY GROUP(1,4)
```

0- - - - - KRUSKAL-WALLIS 1-WAY ANOVA
TOTAL
BY GROUP

MEAN RANK	CASES			
68.98	30	GROUP =	1	GREEN-BL
47.62	30	GROUP =	2	GREEN-WH
62.58	30	GROUP =	3	COLOR-BL
62.82	30	GROUP =	4	COLOR-WH

	120	TOTAL		

			CORRECTED FOR TIES	
CASES	CHI-SQUARE	SIGNIFICANCE	CHI-SQUARE	SIGNIFICANCE
120	6.1402	0.1050	6.2257	0.1011

3. KRUSKAL-WALLIS ANALYSIS OF VARIANCE BY RANKS BY PART FOR EACH MAP DESIGN.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1) GROUP=1
IF (COLOR=1 AND PATTERNS=2) GROUP=2
IF (COLOR=2 AND PATTERNS=1) GROUP=3
IF (COLOR=2 AND PATTERNS=2) GROUP=4
RECODE GROUP (1,2=1) (3,4=2) INTO CGRP
RECODE GROUP (1,3=1) (2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT PART1=P1SCORE1 TO P1SCORE9(1)
COUNT PART2=P2SCOR1 TO P2SCOR10(1)
COUNT PART3=P3SCORE1 TO P3SCORE4(1)
COUNT PART4=P4SCORE1 TO P4SCORE9(1)
COMPUTE TOTAL=PART1+PART2+PART3+PART4
NPAR TESTS K-W=PART1 TO PART4 BY GROUP(1,4)
```

```
0- - - - - KRUSKAL-WALLIS 1-WAY ANOVA
      PART1
   BY GROUP

        MEAN RANK     CASES

            57.93        30     GROUP  =     1    GREEN-BL
            58.05        30     GROUP  =     2    GREEN-WH
            63.12        30     GROUP  =     3    COLOR-BL
            62.90        30     GROUP  =     4    COLOR-WH
                        ---
                        120     TOTAL
                                                         CORRECTED FOR TIES
        CASES     CHI-SQUARE   SIGNIFICANCE     CHI-SQUARE   SIGNIFICANCE
         120        0.6247        0.8907          0.8858        0.8288

0- - - - - KRUSKAL-WALLIS 1-WAY ANOVA
      PART2
   BY GROUP

        MEAN RANK     CASES

            66.47        30     GROUP  =     1    GREEN-BL
            52.40        30     GROUP  =     2    GREEN-WH
            64.28        30     GROUP  =     3    COLOR-BL
            58.85        30     GROUP  =     4    COLOR-WH
                        ---
                        120     TOTAL
                                                         CORRECTED FOR TIES
        CASES     CHI-SQUARE   SIGNIFICANCE     CHI-SQUARE   SIGNIFICANCE
         120        2.9317        0.4023          3.8546        0.2776
```

0- - - - - KRUSKAL-WALLIS 1-WAY ANOVA
PART3
BY GROUP

MEAN RANK	CASES		
54.93	30	GROUP = 1	GREEN-BL
53.57	30	GROUP = 2	GREEN-WH
63.38	30	GROUP = 3	COLOR-BL
70.12	30	GROUP = 4	COLOR-WH

	120	TOTAL	

			CORRECTED FOR TIES	
CASES	CHI-SQUARE	SIGNIFICANCE	CHI-SQUARE	SIGNIFICANCE
120	4.4592	0.2160	5.2417	0.1549

0- - - - - KRUSKAL-WALLIS 1-WAY ANOVA
PART4
BY GROUP

MEAN RANK	CASES		
73.65	30	GROUP = 1	GREEN-BL
48.68	30	GROUP = 2	GREEN-WH
58.82	30	GROUP = 3	COLOR-BL
60.85	30	GROUP = 4	COLOR-WH

	120	TOTAL	

			CORRECTED FOR TIES	
CASES	CHI-SQUARE	SIGNIFICANCE	CHI-SQUARE	SIGNIFICANCE
120	7.8226	0.0498	8.0690	0.0446

4. MANN-WHITNEY U TEST USED TO DETERMINE IF THERE WAS A SIGNIFICANT DIFFERENCE BETWEEN BLACK AND WHITE PATTERNED MAPS.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1) GROUP=1
IF (COLOR=1 AND PATTERNS=2) GROUP=2
IF (COLOR=2 AND PATTERNS=1) GROUP=3
IF (COLOR=2 AND PATTERNS=2) GROUP=4
RECODE GROUP(1,2=1) (3,4=2) INTO CGRP
RECODE GROUP(1,3=1) (2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT PART1=P1SCORE1 TO P1SCORE9(1)
COUNT PART2=P2SCOR1 TO P2SCOR10(1)
COUNT PART3=P3SCORE1 TO P3SCORE4(1)
COUNT PART4=P4SCORE1 TO P4SCORE9(1)
COMPUTE TOTAL=PART1+PART2+PART3+PART4
NPAR TESTS M-W=TOTAL BY PGRP(1,2)

O- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST
     TOTAL
   BY PGRP

        MEAN RANK      CASES

           65.78          60  PGRP = 1.00  BLACK PATTERN
           55.22          60  PGRP = 2.00  WHITE PATTERN
                         ---
                         120  TOTAL
                                          CORRECTED FOR TIES
           U               W                 Z      2-TAILED P
        1483.0          3947.0           -1.6754      0.0939
```

5. MANN-WHITNEY U TEST CONCERNING THE DIFFERENCE BETWEEN AN ORDERED AND UNORDERED COLOR ARRANGEMENT.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
               PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT PART1=P1SCORE1 TO P1SCORE9(1)
COUNT PART2=P2SCOR1 TO P2SCOR10(1)
COUNT PART3=P3SCORE1 TO P3SCORE4(1)
COUNT PART4=P4SCORE1 TO P4SCORE9(1)
COMPUTE TOTAL=PART1+PART2+PART3+PART4
NPAR TESTS M-W=TOTAL BY CGRP(1,2)

0- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST
      TOTAL
   BY CGRP

        MEAN RANK      CASES

           58.30          60  CGRP = 1.00   GREEN
           62.70          60  CGRP = 2.00   COLORED
                         ---
                         120  TOTAL
                                          CORRECTED FOR TIES
            U              W                 Z       2-TAILED P
         1668.0         3498.0           -0.6976       0.4854
```

6. MANN-WHITNEY U TEST USED TO DETERMINE IF THERE WAS A SIGNIFICANT DIFFERENCE IN PERFORMANCE BETWEEN TWO GROUPS WITH VARYING YEARS OF UNIVERSITY EDUCATION.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT PART1=P1SCORE1 TO P1SCORE9(1)
COUNT PART2=P2SCOR1 TO P2SCOR10(1)
COUNT PART3=P3SCORE1 TO P3SCORE4(1)
COUNT PART4=P4SCORE1 TO P4SCORE9(1)
COMPUTE TOTAL=PART1+PART2+PART3+PART4
RECODE YEAR(1,2,3=1)(4,5,6,7,8=2) INTO EXPER
VALUE LABELS EXPER (1) INEXPERIENCED AND (2) EXPERIENCED
NPAR TESTS M-W=TOTAL BY EXPER(1,2)
```

0- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST
TOTAL
BY EXPER

MEAN RANK	CASES		
53.03	63	EXPER = 1.00	INEXPERIENCED AND
68.75	57	EXPER = 2.00	EXPERIENCED
	--		
	120	TOTAL	

		CORRECTED FOR TIES	
U	W	Z	2-TAILED P
1325.0	3919.0	-2.4897	0.0128

7. MANN-WHITNEY U TEST USED TO DETERMINE IF SUBJECTS WITH COURSES IN CARTOGRAPHY WORKED SIGNIFICANTLY BETTER.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                 PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT PART1=P1SCORE1 TO P1SCORE9(1)
COUNT PART2=P2SCOR1 TO P2SCOR10(1)
COUNT PART3=P3SCORE1 TO P3SCORE4(1)
COUNT PART4=P4SCORE1 TO P4SCORE9(1)
COMPUTE TOTAL=PART1+PART2+PART3+PART4
RECODE COURSES(00=1)(01,02,03,04,05,06,07,08,09,10=2) INTO EXPER1
VALUE LABLES EXPER1 (1)INEXPERIENCED (2)EXPERIENCED/
NPAR TESTS M-W=TOTAL BY EXPER1(1,2)
```

```
0- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST
     TOTAL
  BY EXPER1

       MEAN RANK     CASES

          58.45         92  EXPER1 = 1.00  INEXPERIENCED
          67.23         28  EXPER1 = 2.00  EXPERIENCED
                       ---
                       120  TOTAL
                                        CORRECTED FOR TIES
             U               W               Z       2-TAILED P
          1099.5          1882.5         -1.1777       0.2389
```

8. MANN-WHITNEY U TEST USED TO DETERMINE IF PRIOR EXPERIENCE WITH TWO-VARIABLE CHOROPLETH MAPS MADE A SIGNIFICANT DIFFERENCE.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT PART1=P1SCORE1 TO P1SCORE9(1)
COUNT PART2=P2SCOR1 TO P2SCOR10(1)
COUNT PART3=P3SCORE1 TO P3SCORE4(1)
COUNT PART4=P4SCORE1 TO P4SCORE9(1)
COMPUTE TOTAL=PART1+PART2+PART3+PART4
VALUE LABELS MAPS (1) EXPERIENCED (2) INEXPERIENCED/
NPAR TESTS M-W=TOTAL BY MAPS(1,2)
```

0- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST
TOTAL
BY MAPS

MEAN RANK	CASES	
59.78	37	MAPS = 1 EXPERIENCED
60.82	83	MAPS = 2 INEXPERIENCED

	120	TOTAL

		CORRECTED FOR TIES	
U	W	Z	2-TAILED P
1509.0	2212.0	-0.1516	0.8795

9. CROSSTABLES OF RESULTS AT THE ELEMENTARY MAP READING LEVEL.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT ELEM=P1SCORE1(1),P4SCORE1(1)
CROSSTABS TABLES=ELEM BY GROUP
OPTIONS 3,4,5
STATISTICS 1
```

0- - - - - - - - - - - - - - - C R O S S T A B U L A T I O N O F
ELEM BY GROUP

COUNT / ROW PCT / COL PCT / TOT PCT (ELEM)	GREEN-BL 1.00	GREEN-WH 2.00	COLOR-BL 3.00	COLOR-WH 4.00	ROW TOTAL
0.0		1	1		2
		50.0	50.0		1.7
		3.3	3.3		
		.8	.8		
1.00	2	3	2	4	11
	18.2	27.3	18.2	36.4	9.2
	6.7	10.0	6.7	13.3	
	1.7	2.5	1.7	3.3	
2.00	28	26	27	26	107
	26.2	24.3	25.2	24.3	89.2
	93.3	86.7	90.0	86.7	
	23.3	21.7	22.5	21.7	
COLUMN TOTAL	30	30	30	30	120
	25.0	25.0	25.0	25.0	100.0

CHI-SQUARE	D.F.	SIGNIFICANCE	MIN E.F.	CELLS WITH E.F.< 5
3.10280	6	0.7958	0.500	8 OF 12 (66.7%)

NUMBER OF MISSING OBSERVATIONS = 0

10. CROSSTABLES OF RESULTS AT THE INTERMEDIATE MAP READING LEVEL WITHOUT DIVISIONS.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT INTER=P1SCORE2(1),P1SCORE3(1),P1SCORE4(1),P1SCORE5(1),
            P1SCORE6(1),P1SCORE7(1),P1SCORE8(1),P4SCORE2(1),
            P4SCORE3(1),P4SCORE5(1),P4SCORE6(1),P4SCORE7(1),
            P4SCORE8(1),P4SCORE9(1)
IF (INTER LE 8)RESULTS=1
IF (INTER GE 9 AND INTER LE 11)RESULTS=2
IF (INTER GE 12)RESULTS=3
CROSSTABS TABLES=RESULTS BY GROUP
OPTIONS 3,4,5
STATISTICS 1
```

0- - - - - - - - - - - - - - - - C R O S S T A B U L A T I O N   O F
INTER BY GROUP

INTER	COUNT / ROW PCT / COL PCT / TOT PCT	GREEN-BL 1.00	GREEN-WH 2.00	COLOR-BL 3.00	COLOR-WH 4.00	ROW TOTAL
3.00	COUNT				1	1
	ROW PCT				100.0	.8
	COL PCT				3.3	
	TOT PCT				.8	
4.00	COUNT				1	1
	ROW PCT				100.0	.8
	COL PCT				3.3	
	TOT PCT				.8	
7.00	COUNT		2	2	1	5
	ROW PCT		40.0	40.0	20.0	4.2
	COL PCT		6.7	6.7	3.3	
	TOT PCT		1.7	1.7	.8	
8.00	COUNT	3	1	4	1	9
	ROW PCT	33.3	11.1	44.4	11.1	7.5
	COL PCT	10.0	3.3	13.3	3.3	
	TOT PCT	2.5	.8	3.3	.8	
9.00	COUNT	1	3	2	1	7
	ROW PCT	14.3	42.9	28.6	14.3	5.8
	COL PCT	3.3	10.0	6.7	3.3	
	TOT PCT	.8	2.5	1.7	.8	
10.00	COUNT	1	7		4	12
	ROW PCT	8.3	58.3		33.3	10.0
	COL PCT	3.3	23.3		13.3	
	TOT PCT	.8	5.8		3.3	
11.00	COUNT	4	7	5	5	21
	ROW PCT	19.0	33.3	23.8	23.8	17.5
	COL PCT	13.3	23.3	16.7	16.7	
	TOT PCT	3.3	5.8	4.2	4.2	

(CONTINUED)

0- - - - - - - - - - - - - - - C R O S S T A B U L A T I O N O F

INTER BY GROUP

INTER	COUNT / ROW PCT / COL PCT / TOT PCT	GREEN-BL 1.00	GREEN-WH 2.00	COLOR-BL 3.00	COLOR-WH 4.00	ROW TOTAL
12.00	COUNT	9	3	6	6	24
	ROW PCT	37.5	12.5	25.0	25.0	20.0
	COL PCT	30.0	10.0	20.0	20.0	
	TOT PCT	7.5	2.5	5.0	5.0	
13.00	COUNT	7	6	10	3	26
	ROW PCT	26.9	23.1	38.5	11.5	21.7
	COL PCT	23.3	20.0	33.3	10.0	
	TOT PCT	5.8	5.0	8.3	2.5	
14.00	COUNT	5	1	1	7	14
	ROW PCT	35.7	7.1	7.1	50.0	11.7
	COL PCT	16.7	3.3	3.3	23.3	
	TOT PCT	4.2	.8	.8	5.8	
	COLUMN TOTAL	30	30	30	30	120
		25.0	25.0	25.0	25.0	100.0

CHI-SQUARE	D.F.	SIGNIFICANCE	MIN E.F.	CELLS WITH E.F.< 5
38.23663	27	0.0742	0.250	28 OF 40 (70.0%)

NUMBER OF MISSING OBSERVATIONS = 0

f1. CROSSTABLES OF THE RESULTS AT THE INTERMEDIATE MAP READING LEVEL BY DIVISIONS.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT INTER=P1SCORE2(1),P1SCORE3(1),P1SCORE4(1),P1SCORE5(1),
            P1SCORE6(1),P1SCORE7(1),P1SCORE8(1),P4SCORE2(1),
            P4SCORE3(1),P4SCORE5(1),P4SCORE6(1),P4SCORE7(1),
            P4SCORE8(1),P4SCORE9(1)
IF (INTER LE 8)RESULTS=1
IF (INTER GE 9 AND INTER LE 11)RESULTS=2
IF (INTER GE 12)RESULTS=3
CROSSTABS TABLES=RESULTS BY GROUP
OPTIONS 3,4,5
STATISTICS 1
```

0- - - - - - - - - - - - - - - C R O S S T A B U L A T I O N O F
RESULTS BY GROUP

RESULTS	COUNT / ROW PCT / COL PCT / TOT PCT	GROUP GREEN-BL 1.00	GREEN-WH 2.00	COLOR-BL 3.00	COLOR-WH 4.00	ROW TOTAL
1.00		3	3	6	4	16
		18.8	18.8	37.5	25.0	13.3
		10.0	10.0	20.0	13.3	
		2.5	2.5	5.0	3.3	
2.00		6	17	7	10	40
		15.0	42.5	17.5	25.0	33.3
		20.0	56.7	23.3	33.3	
		5.0	14.2	5.8	8.3	
3.00		21	10	17	16	64
		32.8	15.6	26.6	25.0	53.3
		70.0	33.3	56.7	53.3	
		17.5	8.3	14.2	13.3	
	COLUMN TOTAL	30	30	30	30	120
		25.0	25.0	25.0	25.0	100.0

CHI-SQUARE	D.F.	SIGNIFICANCE	MIN E.F.	CELLS WITH E.F.< 5
12.77500	6	0.0468	4.000	4 OF 12 (33.3%)

NUMBER OF MISSING OBSERVATIONS = 0

12. CROSSTABLES OF RESULTS AT THE SUPERIOR MAP READING LEVEL WITHOUT DIVISIONS.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT SUPER=P1SCORE9(1),P3SCORE1(1),P3SCORE2(1),P3SCORE3(1)
            P3SCORE4(1),P4SCORE3(1)
CROSSTABS TABLES=SUPER BY GROUP
OPTIONS 3,4,5
STATISTICS 1
```

0- - - - - C R O S S T A B U L A T I O N O F

SUPER BY GROUP

SUPER	GROUP: COUNT / ROW PCT / COL PCT / TOT PCT	GREEN-BL 1.00	GREEN-WH 2.00	COLOR-BL 3.00	COLOR-WH 4.00	ROW TOTAL
1.00	COUNT		1			1
	ROW PCT		100.0			.8
	COL PCT		3.3			
	TOT PCT		.8			
2.00	COUNT	3	2	2	2	9
	ROW PCT	33.3	22.2	22.2	22.2	7.5
	COL PCT	10.0	6.7	6.7	6.7	
	TOT PCT	2.5	1.7	1.7	1.7	
3.00	COUNT	3	11	7	7	28
	ROW PCT	10.7	39.3	25.0	25.0	23.3
	COL PCT	10.0	36.7	23.3	23.3	
	TOT PCT	2.5	9.2	5.8	5.8	
4.00	COUNT	14	10	10	10	44
	ROW PCT	31.8	22.7	22.7	22.7	36.7
	COL PCT	46.7	33.3	33.3	33.3	
	TOT PCT	11.7	8.3	8.3	8.3	
5.00	COUNT	8	6	9	7	30
	ROW PCT	26.7	20.0	30.0	23.3	25.0
	COL PCT	26.7	20.0	30.0	23.3	
	TOT PCT	6.7	5.0	7.5	5.8	
6.00	COUNT	2		2	4	8
	ROW PCT	25.0		25.0	50.0	6.7
	COL PCT	6.7		6.7	13.3	
	TOT PCT	1.7		1.7	3.3	
	COLUMN TOTAL	30	30	30	30	120
		25.0	25.0	25.0	25.0	100.0

CHI-SQUARE	D.F.	SIGNIFICANCE	MIN E.F.	CELLS WITH E.F.< 5
13.66234	15	0.5513	0.250	12 OF 24 (50.0%)

NUMBER OF MISSING OBSERVATIONS = 0

13. CROSSTABLES OF RESULTS AT THE SUPERIOR MAP READING LEVEL WITH DIVISIONS.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.DAT'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53
  P4SCORE1 TO P4SCORE9 55-63
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE9 (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
COUNT SUPER=P1SCORE9(1),P3SCORE1(1),P3SCORE2(1),P3SCORE3(1)
            P3SCORE4(1),P4SCORE3(1)
IF (SUPER LE 3)RESULTS=1
IF (SUPER GE 4)RESULTS=2
CROSSTABS TABLES=RESULTS BY GROUP
OPTIONS 3,4,5
STATISTICS 1
```

0- - - - - - - - - - - - - - - - - - C R O S S T A B U L A T I O N   O F
RESULTS   BY GROUP

RESULTS	COUNT / ROW PCT / COL PCT / TOT PCT	GREEN-BL 1.00	GREEN-WH 2.00	COLOR-BL 3.00	COLOR-WH 4.00	ROW TOTAL
1.00		6	14	9	9	38
		15.8	36.8	23.7	23.7	31.7
		20.0	46.7	30.0	30.0	
		5.0	11.7	7.5	7.5	
2.00		24	16	21	21	82
		29.3	19.5	25.6	25.6	68.3
		80.0	53.3	70.0	70.0	
		20.0	13.3	17.5	17.5	
COLUMN TOTAL		30	30	30	30	120
		25.0	25.0	25.0	25.0	100.0

CHI-SQUARE	D.F.	SIGNIFICANCE	MIN E.F.	CELLS WITH E.F. < 5
5.08344	3	0.1658	9.500	NONE

NUMBER OF MISSING OBSERVATIONS = 0

14. STATISTICAL RESULTS CONCERNING THE ROLE OF LEARNING EFFECT AS IT APPLIES TO PART 1.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS.NEW'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12 —
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22
  PATTERNS 24 ORDER 26 P1SCORE 28
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE (1)RIGHT (0)WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1)(3,4=2) INTO CGRP
RECODE GROUP(1,3=1)(2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP(1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
             ORDER (1)FIRST (2)LAST/
CROSSTABS TABLES=ORDER BY P1SCORE
OPTIONS 3,4,5
STATISTICS 1
```

CROSSTABULATION OF ORDER ORDER OF PRESENTATION BY P1SCORE

ORDER	COUNT / ROW PCT / COL PCT / TOT PCT	P1SCORE WRONG 0	RIGHT 1	ROW TOTAL
FIRST	1	37	503	540
		6.9	93.1	50.0
		52.1	49.9	
		3.4	46.6	
LAST	2	34	506	540
		6.3	93.7	50.0
		47.9	50.1	
		3.1	46.9	
	COLUMN TOTAL	71	1009	1080
		6.6	93.4	100.0

CHI-SQUARE	D.F.	SIGNIFICANCE	MIN E.F.	CELLS WITH E.F.< 5
0.06030	1	0.8060	35.500	NONE
0.13568	1	0.7126	(BEFORE YATES CORRECTION)	

NUMBER OF MISSING OBSERVATIONS = 0

15. STATISTICAL RESULTS CONCERNING THE ROLE OF LEARNING EFFECTS AS IT APPLIES TO PART 4.

```
TITLE 'MULTI-COMPONENT QUANTITATIVE MAPPING'
FILE HANDLE DATA/NAME='RESULTS4.dat'
DATA LIST FILE=DATA/ID 1-3 SEX 5 AGE 7-8 COURSE 10 YEAR 12
  MAJOR 14-15 COURSES 17-18 MAPS 20 COLOR 22 PATTERNS 24 ORDER 26
  P1SCORE1 TO P1SCORE9 28-36 P2SCOR1 TO P2SCOR5 38-42
  P2SCOR6 TO P2SCOR10 44-48 P3SCORE1 TO P3SCORE4 50-53 P4SCORE 55
VARIABLE LABELS ORDER 'ORDER OF PRESENTATION'
                PATTERNS 'BLACK OR WHITE PATTERNS'
VALUE LABELS SEX 1 'MALE' 2 'FEMALE'/
             MAJOR 1 'GEOGRAPHY'/
             P1SCORE1 TO P4SCORE (1)RIGHT (0) WRONG/
IF (COLOR=1 AND PATTERNS=1)GROUP=1
IF (COLOR=1 AND PATTERNS=2)GROUP=2
IF (COLOR=2 AND PATTERNS=1)GROUP=3
IF (COLOR=2 AND PATTERNS=2)GROUP=4
RECODE GROUP(1,2=1) (3,4=2) INTO CGRP
RECODE GROUP(1,3=1) (2,4=2) INTO PGRP
VALUE LABLES PGRP (1)BLACK PATTERN (2) WHITE PATTERN/
             CGRP (1)GREEN (2)COLORED/
             GROUP (1)GREEN-BL (2)GREEN-WH (3)COLOR-BL (4)COLOR-WH/
             ORDER (1)FIRST (2)LAST/
CROSSTABS TABLES=ORDER BY P4SCORE
OPTIONS 3,4,5
STATISTICS 1
```

0- - - - - - - - - - - - - - - C R O S S T A B U L A T I O N O F
ORDER ORDER OF PRESENTATION BY P4SCORE

ORDER	P4SCORE COUNT / ROW PCT / COL PCT / TOT PCT	WRONG 0	RIGHT 1	ROW TOTAL
FIRST	1	199	341	540
		36.9	63.1	50.0
		62.2	44.9	
		18.4	31.6	
LAST	2	121	419	540
		22.4	77.6	50.0
		37.8	55.1	
		11.2	38.8	
	COLUMN TOTAL	320	760	1080
		29.6	70.4	100.0

CHI-SQUARE	D.F.	SIGNIFICANCE	MIN E.F.	CELLS WITH E.F. < 5
26.32944	1	0.0000	160.000	NONE
27.01776	1	0.0000	(BEFORE YATES CORRECTION)	

NUMBER OF MISSING OBSERVATIONS = 0

References

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