This is to certify that the

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USING ANIMATION TO IMPROVE THE COMMUNICATIVE ASPECTS
OF CARTOGRAMS

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Jennifer Alea Ware

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M.A. degree in Geography

Judy M. Olson
Major professor

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USING ANIMATION TO IMPROVE THE COMMUNICATIVE ASPECT OF CARTOGRAMS

By

Jennifer Alea Ware

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ABSTRACT

USING ANIMATION TO IMPROVE THE COMMUNICATIVE ASPECT OF CARTOGRAMS

By

Jennifer Alea Ware

The message of a cartogram is often lost if the reader is unfamiliar with the underlying base map. The question asked in this research is whether allowing the reader to view and control the cartographic transformation between geographic space and cartogram space aids in conveying information.

In this study, cartograms of a familiar region and an unfamiliar region were presented in three formats: traditional (static), automatic animation, and user-controlled animation. Subjects were asked questions about the transformations occurring in each cartogram.

The results showed that familiarity was most important when using cartograms in the still format. The animated formats produced higher mean scores than the still format, and there was a significant interaction effect between familiarity and format. The greatest improvement was between the mean scores for the unfamiliar region's still and animation formats.

To my husband Rob Blanchard,
for his unceasing love and support.

ACKNOWLEDGEMENTS

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I thank my parents, John and Jacqueline Ware, for instilling in me the importance of education and for their support and encouragement in all my endeavors.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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Chapter 1

INTRODUCTION

Introduction

Computer technology has opened the door to new possibilities in the realm of geography, especially in the cartographic field. Manual methods of mapmaking are effectively obsolete, given the automation capabilities of the computer. Olson (1997) writes that "computer usage in mapping has become the norm, it is considerably easier than mapping with manual methods, and it is at least of comparable quality." The question remains, however, have any real advances been made beyond the shortening of time needed to make a map?

In the early 1990s, researchers felt that the computer continued to be used to replicate manually made maps with all their inherent limitations (Peterson 1993). Karl (1992) stated, "the use of computers in cartography offers new forms of information display. However, because we are still fixated on the traditional map, we overlook this potential and use computers predominately to mimic manual methods."

Today, in the late 1990s, the proliferation of the World Wide Web and the availability of multimedia facilities have created new territory in cartography. The computer is used to make maps that are designed to be seen and used

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primarily on the computer screen. Monmonier (1985), in writing about the technological transition in cartography, said that "maps should be viewed as software rather than material objects." To some extent, this belief has been accepted.

Though maps are now being made specifically for use on computers, exploration of the computer's ability to add new dimensions, such as animation, to maps has been slow. Campbell and Egbert (1990) reviewed the evolution of animated cartography and discussed its stunted progress. A few notable historical examples of animated maps include Tobler's (1970) growth of a city, Moellering's (1973) traffic accidents, and Weber and Buttenfield's (1993) surface temperatures in the U.S. More animated maps are being produced now than in the past, but they are still not commonly seen and used. Research needs to be done with different map types to determine their possibilities for cartographic animation (Karl 1992). Little research has been done with cartograms.

The construction of cartograms through computer algorithms has received some attention (Tobler 1973, Dougenik et al. 1985, Gusein-Zade and Tikunov 1993, Jackel 1997a), but once completed, the final product is no different from a manually constructed cartogram. Jackel (1997b) has experimented with animating cartograms, but

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adding animation to cartograms is an exception rather than the rule. Adding animation moves beyond using the computer to create a traditional cartogram product. The purpose of this research is to determine if adding animation to cartograms is an appropriate and advantageous use of the computer's capabilities.

Types of cartograms

To understand the different types of cartograms, one must first have an understanding of the general form. A cartogram is a map on which distances or areas are proportionate to some variable of interest other than geographic distances or areas. A transformation occurs between geographic space and cartogram space. "In these abstractions from reality, ordinary geographical area, orientation, and contiguity relationships are lost. The reader is forced to look at a twisted and distorted image that only vaguely resembles the geographic map" (Dent 1993). As a result, cartograms are often difficult to interpret. Visual cues that may help the reader include labels on places or enumeration units and an inset of the geographic base map.

Cartograms can take several different forms. At the most basic level is the linear vs. areal distinction. On linear cartograms, distances represent something other than earth distance. The most commonly known examples of linear cartograms are subway maps and some road maps (Kadmon 1982). Geographic accuracy is sacrificed in favor of an abstract though topologically correct rendition **(Figure 1)**.

On an areal cartogram, areas represent something other than earth area. Areal cartograms are more prevalent, and they can be either contiguous or noncontiguous. Noncontiguous cartograms retain the shapes of the individual enumeration units, changing only their size **(Figure 2)**. They are much easier to construct, requiring only linear scale changes, but they do not preserve boundary relationships (Olson 1976). Contiguous cartograms maintain boundary relationships, but the shapes of individual enumeration units are distorted **(Figure 3)**. The major difficulty in using contiguous cartograms is that the distortion may make it difficult for the reader to make the connection back to geographic space, even with the addition of visual cues (Dent 1993).

Cartograms are used most effectively when they differ greatly from the underlying geographic map. Their main advantage is that they abrogate the visual dominance of larger enumeration units (Olson 1976). They allow the data, rather than land area, to determine the importance of each enumeration unit. However, this means that their success depends on readers' familiarity with the geographic map.

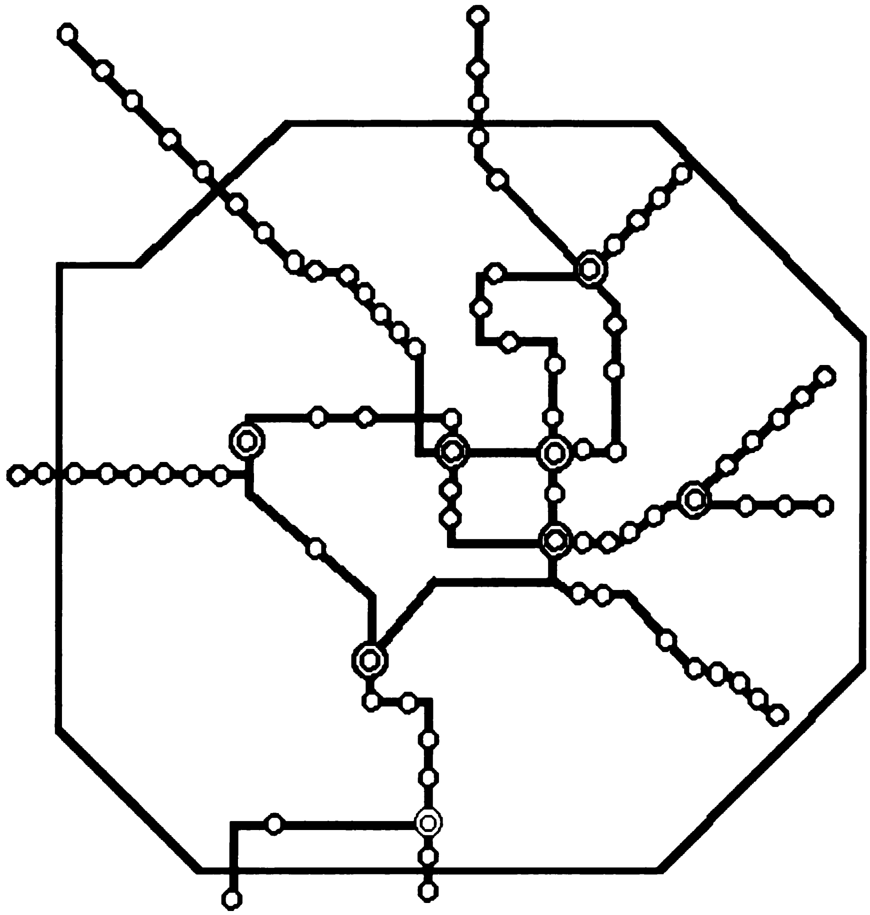

Figure 1. Example of a linear cartogram.
Based on a map of the Washington D.C. Metrorail system created by the Washington Metropolitan Area Transit Authority. Simplified by the author.

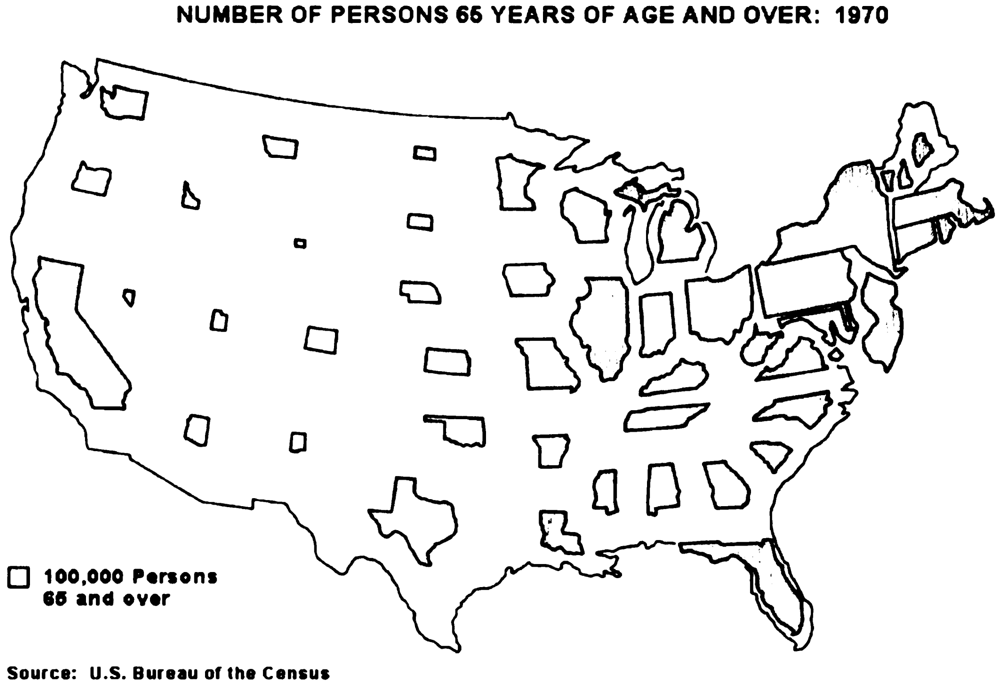

Figure 2. Example of a noncontiguous cartogram.
Created by Judy M. Olson.

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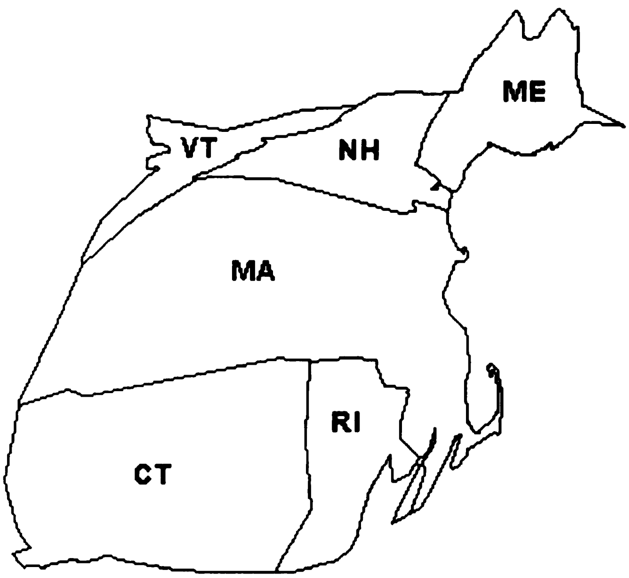

Figure 3. Example of a contiguous cartogram.
Map showing the number of births in New England.
Created by the author.

The fact that Maine is much smaller than Massachusetts on this cartogram of births can have little impact on a reader who is not aware of the states' actual geographic size.

The term "cartogram" in the remainder of this thesis will refer to the contiguous value-by-area cartogram, where the enumeration units retain their topological relationships

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and the area of the enumeration unit represents the value of the attribute being mapped.

Animation and cartograms

Animation is generally used in cartography to represent change over time. For example, a series of maps showing population at discrete points in time can be rapidly displayed in sequence to portray the illusion of movement of the population. Migratory patterns of distribution can be detected. Peterson (1993) states that although "cartographic animation is predominately associated with the representation of change over time...[it is] useful for other purposes as well, such as depicting the deformation caused by a map projection." A cartogram by its nature undergoes such deformation, and animation can show the change from geographic map to cartogram and vice versa.

The deformation of a geographic map into a cartogram can be called a metamorphosis. Gersmehl (1990) describes metamorphosis as "defining an object with a series of points and placing those points in their appropriate starting and ending positions...The computer's job is to calculate the position for each 'in-between' frame of an animation." This process of creating in-between frames is called "morphing." Through animation, the geographic map will appear to morph into the cartogram.

Overview of the research

This research is primarily concerned with testing the communicative aspects of contiguous cartograms that may be affected by adding animation. It is not concerned with developing a new way to construct cartograms, since automation of that process has already been developed.

Griffin (1983) states that "the full communicative impact of a cartogram will be achieved only if the users are able to relate cartogram space to geographic space." This process is especially difficult with contiguous cartograms. Allowing the reader to view and control the transformation between cartogram space and geographic space with the use of animation may lead to greater comprehension of the cartogram's message. The general idea of this research is that the addition of animation to a cartogram will improve its communicative function, especially with non-familiar regions. If this hypothesis can be supported, it will mean that cartograms may be used more often and with a wider variety of regions.

Chapter 2

LITERATURE REVIEW

Brief history of cartograms

It is difficult to determine when cartograms first came into existence. Kadmon (1982) cites the Peutinger Map, a 12th century copy of a Roman road map dating from the fourth century, as one of the oldest known examples. Cartograms came into general use in various European countries in the late nineteenth century, as reported by Hunter and Young (1968). They are known by different names in different countries: the French "anamorphose," the German "Kartogramm," and the Russian "varivalent projection" (Kadmon 1982, Tobler 1986).

In the 1930s Edwin Raisz was one of the first American cartographers to make use of cartograms. Raisz's (1934) rectangular cartograms of the United States were contiguous, maintaining boundary relationships but not retaining shapes of individual enumeration units. Text labels were required to denote specific units; otherwise the reader would have no way of determining which rectangle corresponded to which state. Raisz's focus was not on comparing the cartogram to geographic space; he did not view the cartogram as a true map but as a simple geometric design to visualize spatial relationships in statistical data.

Until the 1950s, cartograms were seen as a combination of maps and graphs, showing both comparative proportion and relative position of enumeration units. Several researchers suggested that it might be possible to preserve the approximate shape of individual units while maintaining topology (Harris 1955, Tobler 1963), and rough approximations had been attempted (Woytinsky and Woytinsky 1953). Briefly, topology is the configuration of nodes, lines and connections, which means that on a topologically correct area cartogram, an enumeration unit has all the same neighbors that it has on the earth's surface. The idea of truly maintaining topology, however, produced a severe challenge for maintaining recognizability of shapes.

Shape recognition

Since the sizes and possibly positions of enumeration units in a contiguous cartogram are changed from geographic reality, it is important that the shape of the unit remain recognizable in order to facilitate communication. Olson (1976) writes, "the success of the visual representation...depends, in fact, on the reader's recognition of the units shown." Shape has been primarily used as a descriptive device in geography (Boyce 1964). Various approaches have been taken towards understanding two-dimensional shape recognition (Quinlan 1991).

Conflicting theories (Attneave 1954, Kennedy and Domander 1985) exist about whether the most useful aids in the recognition of shapes are the points of maximum change or the points of minimum change.

Cartographers giving attention to the matter have concluded that the points of maximum change are most important to shape recognition, at least on maps. In 1972, Borden Dent studied the importance of shape, specifically in relation to cartogram communication. Dent's experiments revealed that map readers mentally generalize shapes by using "information points," places on the outline where the shape changes direction. He concluded, "those elements of the original shapes that truly define it should be preserved to give the map reader the visual cues necessary to identify the new shape. In this way, mental transferal from previously-learned shapes to the more unconventional ones of the cartogram will be easier and more reliable" (Dent 1972).

Cartograms and communication

Cartograms have been used to map a wide variety of topics, including population, economic variables, and electoral vote distribution (Raisz 1934, Getis 1963, Dorling 1994). They can be seen in atlases, textbooks and magazine articles. However, few researchers have assessed the communicative success of the cartogram.

In 1975, Dent focused on the communicative aspects of value-by-area cartograms. Subjects were asked to evaluate a proportional circles map and a cartogram, each displaying the same information, by using a semantic differential test. Using polar opposite words or phrases (such as easy to read vs. hard to read, innovative vs. conventional) in three categories (general attitudes, appearance, and readability), subjects marked on a continuum where they judged each map to fall. The results were surprising. Though cartographers feel, according to Dent, that the proportional circles map is a conventional technique, subjects felt both it and the cartogram were innovative and unusual. Subjects also felt both maps communicated their messages effectively and symbolized the information well, but the cartogram was rated harder to read than the proportional circles map.

Dent's (1975) model of cartogram communication between cartographer and reader **(Figure 4)** lends itself to the goals of this paper. He outlines six steps taken by the reader and six corresponding steps taken by the cartographer. In animating the cartogram, the problem of subjects' not adequately or correctly performing the mental transformations necessary to cartogram interpretation is eliminated through the modification of several steps.

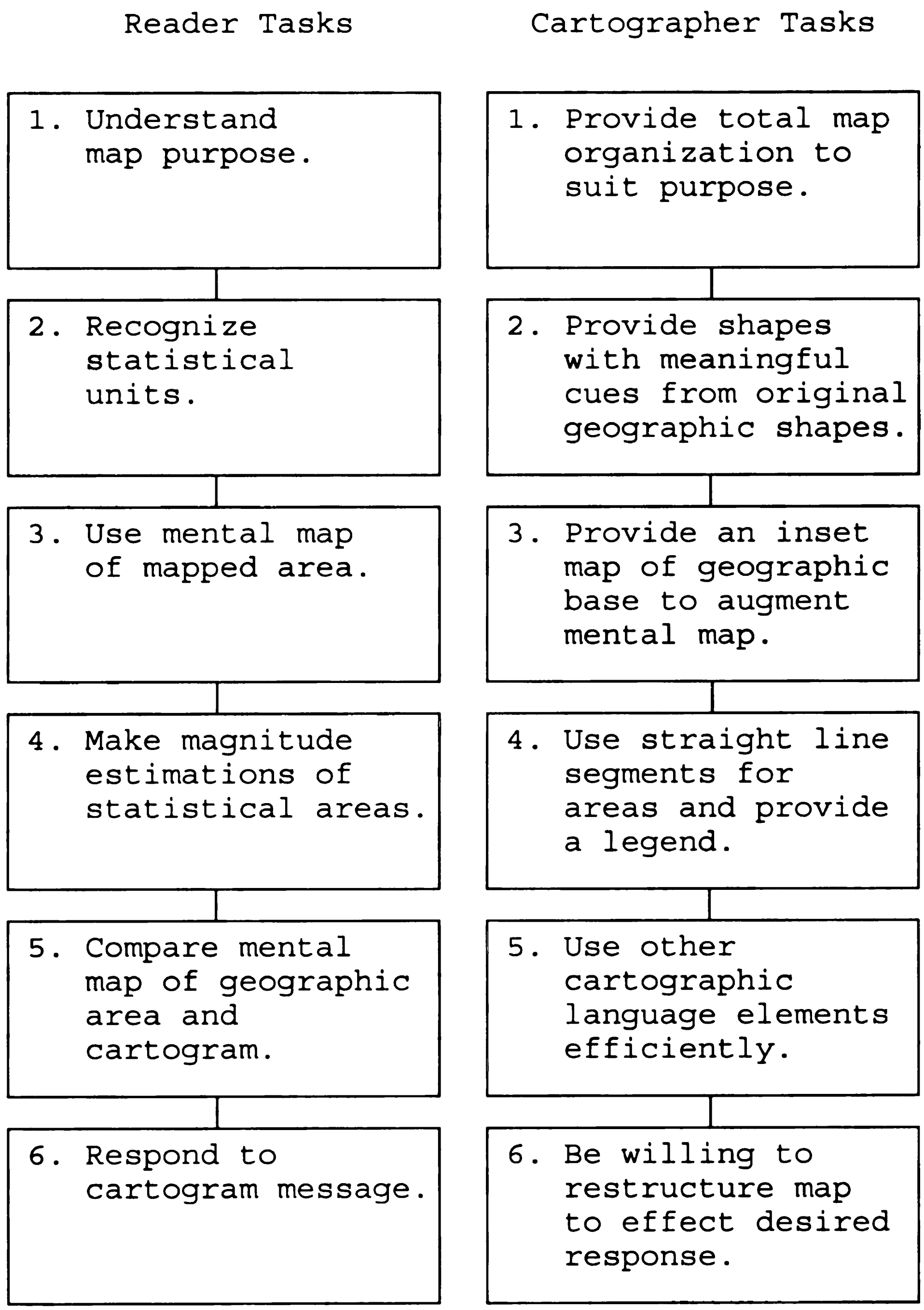

Figure 4. Dent's model.

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In step 3, the readers will not be required to have a mental map of the area, since they will be able to view the geographic area at the scale of the cartogram instead of using an inset map at a different scale. Step 4 as an explicit task has been eliminated in the research design; the readers will not be required to make absolute magnitude estimations of statistical areas. In step 5, the cartographer will use animation instead of traditional cartographic language elements to facilitate comparison between the geographic area and the cartogram.

T.L.C. Griffin in 1983 "examine[d] the user's ability to achieve the intellectual transformation so essential to cartogram use." Griffin tested subjects' ability to recognize areal units on topological (contiguous, value-by-area) cartograms. Subjects were shown a geographic map of the electoral subdivisions of Adelaide, Australia, or a cartogram where the subdivisions had been spatially transformed according to population values. For each round of the experiment, one map, either the geographic map or the cartogram, was designated the task display. The opposite one was designated the target display. Certain units were marked with letters on the task display, and subjects were required to find the corresponding unit on the target display. Griffin recorded both correctness and location of the response. Location was measured angularly from the centroid of each correct unit.

Although the error rate in responses was high at 23%, the spatial pattern of the errors revealed that two map transformation qualities were affecting the responses: change in angular location of units and change in each unit's shape. The subjects were able to locate faster the units on the cartogram when first shown the map than they were able to locate units on the map when first shown the cartogram.

It is not surprising that angular and shape changes affected speed, but the reason for the cartogram-to-map difficulty is not easily explained. Griffin suggested the subjects were not adequately compensating mentally for the cartogram distortion. If this factor can be alleviated or controlled, cartogram communication should improve. Allowing the reader to view and control the transformation between geographic space and cartogram space through the use of animation will obviate the need for the reader to mentally visualize the distortion transformation.

More recently, Rittschof et al. (1996) demonstrated that familiarity with the geographic area depicted in a cartogram is a vital part of the cartogram's ability to communicate. Subjects were asked to reconstruct geographic maps and cartograms of a familiar region and an unfamiliar region after being shown these maps for a brief period of time. Short-term familiarity with a region, as defined by viewing a geographic map immediately preceding a cartogram, resulted in less accurate recreations than long-term familiarity. Rittschof et al. concluded that the "true, earth-centered scale" of a region, such as an inset map, should be provided to prevent subjects' mental maps from becoming distorted by viewing the cartograms. Since the geographic map will morph into the cartogram in this research, subjects will be able to view the geographic map as many times as necessary and in conjunction with the cartogram. Long-term familiarity with the geographic area is not expected to be a requirement due to the use of animation.

Animation and maps

The first suggestions that animation might be useful when combined with maps came from Thrower (1959). Examples of animated maps are varied (Tobler 1970, Moellering 1973, Weber and Buttenfield 1993). Progress has not been as smooth as one might expect, hindered by factors such as costs to produce, difficulty in distribution, and the complexity of conditions involved in proper and effective use of animation. Progress in animating maps is also closely tied to development of the proper technology

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(Campbell and Egbert 1990). There are still many issues to explore in animated cartography. DiBiase et al. (1992) suggested that animation could be used to complement spatially abstract maps, such as cartograms.

In the more general literature, much experimentation has been done to investigate how animation affects comprehension and learning. No clear case for or against animation has emerged, possibly due to the wide variety of conditions and topics for which animation is used (Park and Hopkins 1993). However, some standardization of the guidelines for using animation has occurred. One pertinent guideline states that animation should be used "when the instruction requires visualization, particularly with spatially oriented information" (Milheim 1993). A seminar study with a physical geography animation supported this conclusion; the only question on which subjects performed significantly better was one that required visualization of movement (Ware 1997). Maps by definition contain spatially oriented information, and cartograms by their nature require visualization of the transformation from geographic space.

Problem statement and hypotheses

Cartograms have traditionally been viewed as difficult to interpret and as a result are rarely used. This research is attempting to alleviate the difficulties caused by readers' inability to adequately perform mentally the transformation between geographic space and cartogram space by allowing the reader to view and even control the transformation in the form of an animation. The problem is to determine whether adding this animation to a cartogram will improve its communicative function over the traditional presentation of such maps, and whether the addition of animation is even more effective with a map of an unfamiliar region.

Dent (1975) states that "it is only by recognizing the discrepancy between [the cartogram] and geographic reality that the reader is able to absorb the map message." Griffin (1983) also states that "the full communicative impact of a cartogram will be achieved only if the users are able to relate cartogram space to geographic space." The hypothesis of this research is that allowing the reader to view the transformation of a cartogram through animation will improve its communicative function, especially with non-familiar regions. Cartograms may become more widely used if they can communicate more effectively.

Chapter 3

METHODS

Overall design and expected results

It will be useful to give an overall picture of the design of the experiment and the expected results first. Each set of choices in the experimental design will then be discussed in turn.

To test the effects of animation on the communicative aspects of cartograms, a set of twelve cartograms was created **(Figure 5)**. Two regions were selected, a familiar area and a lesser-known area. Two variables were chosen to be mapped. Three formats were used to present the cartograms: a still or non-animated layout, automatic animation through the use of a "play" button, and manual animation through the use of a slider bar. Three questions were asked of each cartogram and the response and response time were recorded for each question.

The familiar region was expected to have higher overall mean scores than the unfamiliar region, especially on the still format questions. For each region, the best performance was expected on questions following the use of a slider bar to present the cartograms because this format gives the reader both the ability to view the transformation and to control its speed and direction (forward or reverse).

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Presentation Formats

	Still	Play	Slider
Familiar Region: United States	Population	Population	Population
	Cattle	Cattle	Cattle
Unfamiliar Region: China	Population	Population	Population
	Cattle	Cattle	Cattle

Figure 5. Test cartograms.

The lowest performance was expected on questions using the still format to present the cartograms because this format requires the reader to mentally perform the transformation and gives no other visual aids or cues.

Overall, higher scores were expected on the animated questions than the still questions.

The addition of animation to a cartogram of an unfamiliar region was expected to have more of an effect on cartogram communication than the addition of animation to a cartogram of a familiar region.

Subjects were expected to feel they spent less time answering the questions for animated cartograms than they spent answering the questions for still cartograms. In reality it is likely that the subjects would spend more time answering the questions for animated cartograms because they had the ability to play and replay the animation many times.

Selecting the regions to map

To appreciate the distortion occurring in a cartogram, the reader must have some knowledge of the geographic base map. If this knowledge is ingrained, that is, if the reader has a strong mental image of the geographic map, then conventional wisdom suggests that the only requirement is to look directly at the cartogram. The reader should be able to visualize the geographic map and mentally compare it with the cartogram. This process may not be as automatic as might be expected. It is possible to see an object and recognize that some aspect has changed but be unable to pinpoint the exact nature of the change. In the same fashion, a reader might look at a cartogram and recognize that it looks different from a geographic map but be unable to determine in what way it is different. In other words, it is only a hypothesis and not a foregone conclusion that familiarity with the geographic area makes reading a cartogram easier.

If knowledge of the geographic space is not ingrained, that is, if the reader does not have a strong mental image of the geographic map, then additional visual cues are required to facilitate comparison with the cartogram. The most common visual cue is an inset of the geographic map. The reader is required to perform eye movement between the inset map and the cartogram, as well as process a mental scale change if the inset map is different in size from the cartogram. These additional tasks presumably make interpretation slower and possibly less correct when a cartogram depicts an unfamiliar region. If the reader were able to view the transformation between geographic space and cartogram space, with both depictions at the same scale, perhaps comprehension would be faster and interpretation more correct.

This research is taking place in the United States and the majority of the subjects are likely to be long-term residents of the U.S. As such, they have probably had lengthy exposure to its geographic map and the shapes of individual states. For this reason, the continental United States was chosen as the "familiar" region **(Figure 6)**. Subjects were expected to have a strong mental map of the United States. The term "states" will refer to states and the District of Columbia.

The country of the People's Republic of China, hereafter referred to simply as "China," is approximately the same area as the United States, and it has a similar administrative hierarchy. China's mutually exclusive set of provinces, municipalities and autonomous regions, are parallel to American states. The term "provinces" will collectively apply to this set of divisions. While some subjects may have a strong mental map of China as a whole, they are unlikely to have a strong mental map of China's individual provinces. China was chosen as likely being "unfamiliar" to subjects **(Figure 7)**.

The base map of China was obtained online from the China Data Center at the University of Michigan (Liu, Xurong and Lavely et al., 1996) in ArcInfo export format. The map was downloaded and imported into ArcView, then converted to a shapefile. The base map of the United States was obtained online from the National Oceanic and Atmospheric Administration (1996) in shapefile format. The map was downloaded and brought into ArcView.

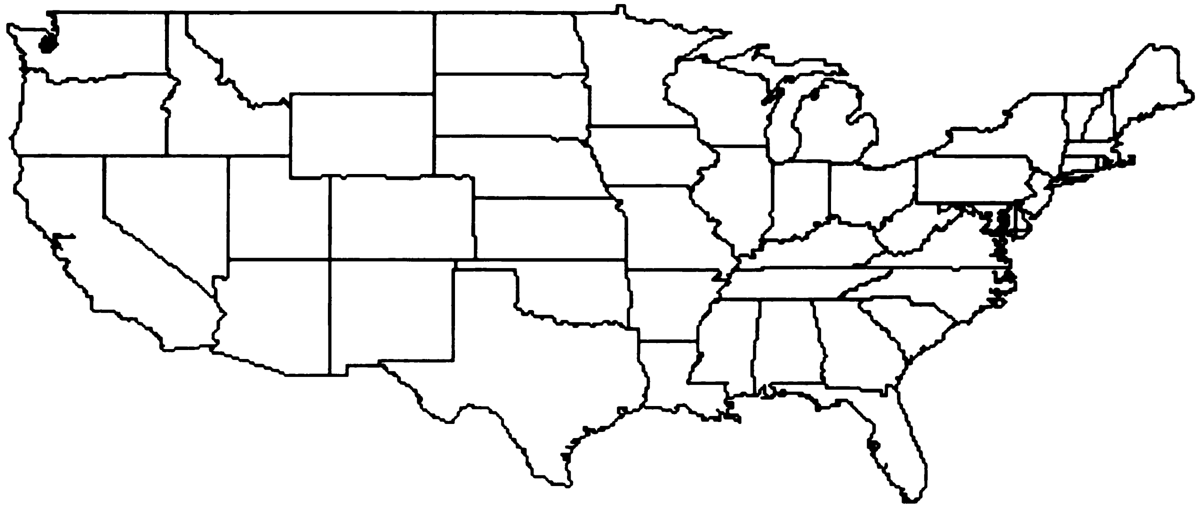


Figure 6. Geographic map of the United States.
Map shows the forty-eight continental states and the District of Columbia.

Figure 7. Geographic map of China.
Map shows the thirty provinces, municipalities and autonomous regions.

Selecting the attributes to map

Selecting attributes for cartogram representation requires careful thought. The essence of the cartogram is its distortion from the geographic map. If little or no distortion occurs, the purpose of the cartogram is lost. Analyzing the data prior to cartogram construction prevents this unwanted result. A simple correlation analysis can be performed between the rank orders of the land area percentage of each enumeration unit and its attribute percentage. Using the total amount of land area and the total amount of the attribute, each enumeration unit is assigned a percentage according to its proportion of the total. If the rank orders correlate, then the attribute is inappropriate, as the cartogram will look very similar to the geographic map.

In this particular testing environment, an additional criterion needed to be met. Two variables were used in the testing program. The two variables were required to produce a sample, albeit small, of different-looking cartograms; therefore, the attribute percentages could not have rank correlations with one other that were close to 1.00.

Population was the most obvious attribute to select, since it does not generally correlate with land area. Selecting a second attribute that met all the above criteria was not an easy task. Various possibilities were considered, including per capita income, number of illiterate persons, and acres of cropland. Eventually, number of beef cattle was chosen. The data did not exactly compare across the two countries because China recorded the number of cattle slaughtered while the United States recorded the number of beef cattle. This was accepted as a close enough match for the purposes of this research, and the attribute was given the common name "number of cattle."

The attribute data for the United States were obtained online from the U.S. Census Bureau (1992) and the National Agricultural Statistics Service (1992) **(Table 1)**. The attribute data for China were obtained online from the China Data Center (Skinner et al. 1997) and the Agricultural Statistical Database of the People's Republic of China (Colby, Cook and Webb, 1998) **(Table 2)**.

The Spearman's rank order correlation test was calculated on the ranked percentages of area, population, and cattle. Not surprisingly, area and cattle were the most highly correlated, but none of the variables were strongly correlated (near 1.00) with each other in either region **(Table 3)**.

Table 1. United States data.

Name	Population	Cattle
Alabama	4040587	771151
Arizona	3665228	292848
Arkansas	2350725	826306
California	29760021	862971
Colorado	3294394	900347
Connecticut	3287116	6878
Delaware	666168	2856
District of Columbia	606900	0
Florida	12937926	962527
Georgia	6478216	599899
Idaho	1006749	565016
Illinois	11430602	447201
Indiana	5544159	293836
Iowa	2776755	1065744
Kansas	2477574	1434017
Kentucky	3685296	1088532
Louisiana	4219973	441725
Maine	1227928	11412
Maryland	4781468	51676
Massachusetts	6016425	7347
Michigan	9295297	116106
Mississippi	2573216	588920
Missouri	5117073	1876845
Montana	799065	1506445
Nebraska	1578385	1857341
Nevada	1201833	265690
New Hampshire	1109252	3727
New Jersey	7730188	12280
New Mexico	1515069	631738
New York	17990455	72971
North Carolina	6628637	385428
North Dakota	638800	837716

Table 1 (cont'd).

Name	Population	Cattle
Ohio	10847115	272920
Oklahoma	3145585	1728273
Oregon	2842321	629625
Pennsylvania	11881643	157773
Rhode Island	1003464	967
South Carolina	3486703	222566
South Dakota	696004	1604838
Tennessee	4877185	988550
Texas	16986510	5186359
Utah	1722850	356971
Vermont	562758	11812
Virginia	6187358	674068
Washington	4866692	310554
West Virginia	1793477	197886
Wisconsin	4891769	195810
Wyoming	453588	746789

Table 2. China data.

Name	Population	Cattle
Anhui	56181005	968000
Beijing	10819414	69000
Fujian	30048275	96000
Gansu	22371086	508000
Guangdong	62829737	452000
Guangxi Zhuang	42244884	553000
Guizhou	32391051	383000
Hainan	6182833	146000
Hebei	61089196	780000
Heilongjiang	35215953	577000
Henan	85534200	2208000
Hubei	53970501	241000
Hunan	60561433	265000
Jiangsu	67056812	165000
Jiangxi	37710277	270000
Jilin	24659785	560000
Liaoning	38930683	417000
Nei Mongol	21456518	737000
Ningxia Hui	4655445	54000
Qinghai	4456952	755000
Shaanxi	32882286	338000
Shandong	84392104	1673000
Shanghai	13341852	1000
Shanxi	28758846	258000
Sichuan	107218310	933000
Tianjin	8785427	52000
Xinjiang Uygur	15156883	819000
Xizang	2196029	472000
Yunnan	36972587	383000
Zhejiang	41635642	59000

Table 3. Rank correlation of variables.

Region	Variable 1	Variable 2	Spearman's r
United States	Area	Population	0.110
	Area	Cattle	0.698
	Population	Cattle	0.133
China	Area	Population	0.187
	Area	Cattle	0.541
	Population	Cattle	0.257

Constructing the cartograms

Currently, the author is aware of no commercial software program on the market that constructs cartograms. Custom programs have been written in various languages (Tobler 1973, Dougenik et al. 1985, Gusein-Zade and Tikunov 1993, Jackel 1997a). The method chosen for this project was Jackel's 1997 program, which translates the Dougenik et al. 1985 contiguous cartogram algorithm into the Avenue programming language for use in the ArcView GIS environment **(Appendix A)**.

The program calculates the force exerted by the centroid or center point of each polygon on each perimeter point in each polygon and adjusts each perimeter point's location accordingly. The force, based on gravitational pull, is dependent on the polygon's attribute value and the distance between the centroid and each perimeter point. A centroid has a stronger effect on nearer points than on farther points. The user chooses the number of iterations to perform. As the number of iterations increases, the error between the desired area and the actual area decreases. Eventually, a limit is reached where performing more iterations will not produce visible distortion and will not lower the error by any meaningful amount. The output is a standard ArcView shapefile produced at the conclusion of each iteration.

The program requires the geographic data to be in the form of an ArcView polygon shapefile as well. Since the program computes the force on each point individually, the program is extremely calculation intensive, and the more points a shapefile has, the longer it will take to process.

The GIS data from which the United States and China shapefiles originated had a much higher resolution than was needed for the test maps. The shapefiles contained well over 100,000 points each, too many to run the cartogram creation program in a feasible amount of time. The shapefiles were generalized in ArcInfo using the "GENERALIZE" command with the "BENDSIMPLIFY" option.

The preservation of the shapes of individual enumeration units is a key factor that enables cartograms to communicate their messages (Dent 1972). Although topology or contiguity is maintained perfectly, the size of the unit is changing to reflect data values, and the better the shape is maintained the easier it is to recognize identity of units. To maintain shape in the cartogram transformation, the geographic base map must start with well-defined shapes. A balance must be struck between reducing the number of points to take the map to a manageable level, and maintaining good shape for each enumeration unit. The tolerance in the "GENERALIZE" command was varied until the number of points was substantially reduced, yet recognizable enumeration units were retained.

The United States shapefile was reduced to approximately 9,000 points and the China shapefile to about 25,000 points. Even with this significant decrease in the number of points, running the program took about four and six hours for the United States and China respectively.

The attribute values must also meet certain guidelines (Dougenik et al. 1985). No polygon may have a value of zero. The District of Columbia has zero cattle, but its area was merged with Maryland for the construction of the cattle cartogram. If an enumeration unit is made up of more than one polygon (for example, the state of Michigan, which has an Upper and Lower Peninsula), then its attribute value must be distributed among its polygons proportionate to the area of each polygon.

Though China has thirty provinces, the shapefile contained 298 polygons. Most of the coastal provinces are made up of a large mainland and many smaller islands. These islands would not be visible at the scale of the test maps and were deleted. Two provinces had multiple polygons that were large enough to be retained, for a total number of thirty-two polygons in the shapefile. The continental United States has forty-nine states, but the shapefile contained 1268 polygons. Again, many small islands were deleted. Three states had multiple polygons large enough to be retained, for a total number of fifty-two polygons in the shapefile.

If the data have too wide a range between extremes, then the polygons with the smallest data values may have problems distorting correctly. The distortion of their points may be so great that the polygon overlaps itself. If this happens, then the program treats this newly created sliver as the enumeration unit. The program completes its iterations, but for some indiscernible reason, no further distortion occurs. This problem occurred several times, but was eliminated by making slight adjustments to the locations of several points in the shapefiles.

Creating the cartogram test

A total of four cartograms were created in the PC ArcView environment **(Figures 8-11)**. For the population cartograms, the number of iterations needed was twelve. For the cattle cartograms, the number of iterations needed was eight. An extra cartogram of births in the New England region of the United States **(Figure 3)** was created for the introduction. This cartogram required twelve iterations. The output for each cartogram was a series of shapefiles, one per iteration. Each shapefile was imported into Macromedia Freehand where its size was reduced to 75% to fit on the testing screen. The shapefiles were then exported as GIFs and imported into Macromedia Director.

Macromedia Director was chosen as the software with which to design the cartogram test because of its multimedia, animation and interactive capabilities as well as its availability at Michigan State University. Macromedia Director is commonly used for a wide variety of multimedia applications. Director also has the ability to create "projectors" which run independently of the Director software, allowing products to be used even on computers that do not have Director installed.

Figure 8. Cartogram of population, United States.

Figure 9. Cartogram of cattle, United States.

Each shapefile was a "cast member" or a unique bitmap graphic and was placed in its own frame or cell. When viewed in rapid succession, the geographic map appears to be morphing into the cartogram. The more frames, the smoother the animation appears. With limits of twelve and eight frames, the animations were not as smooth as intended, but definitely sufficient to portray a visible morphing effect.

The test was designed to present the cartograms in three formats for purposes of comparing each format's effectiveness in communication **(Figures 12-16)**. All formats displayed a basic layout consisting of the geographic base map and the cartogram at the same scale on the same screen. A "still" format was the basic layout only, where the cartogram was displayed in its final iteration **(Figure 12)**.

A "play" format was the basic layout with the addition of "play" and "rewind" buttons. The cartogram was first displayed at zero iterations, matching the base map on the other side of the screen **(Figure 13)**. The reader was able to click "play" to watch the cartogram automatically transform in a continuous, relatively smooth movement. The end display was the cartogram in its final iteration **(Figure 14)**. The reader was also able to click "rewind" to watch the transformation in reverse and return to the zero iteration. This format allowed the reader to view the transformation in either direction, but did not allow control of the speed of the transformation.

A "slider" format was the basic layout with the addition of a slider bar, containing a draggable icon that gave the reader control over the viewing of the transformation. The cartogram was again first displayed at zero iterations **(Figure 15)**. The reader was then able to drag the icon to view the cartogram at any intermediate stage between the base map and the cartogram in its final iteration **(Figure 16)**. This arrangement allowed the reader to control both the speed and direction of the transformation.

The cartograms and geographic maps were given titles to distinguish between them and to tell the reader what variable was being presented. No other labeling, such as of individual states or provinces was provided on any of the maps. The maps were displayed as black-and-white linework. Using a color scheme would have provided the reader with an unwanted (in this research) additional visual cue. No legend was given, because subjects were not asked to obtain absolute quantitative data from the maps.

A total of twelve cartograms were used in the test program. Two cartograms were created of each region, the United States and China, using the two variables of population and cattle. Each region and variable was presented in each one of the three formats: still, play animation and slider animation. The twelve cartograms were divided into two sets by region. The United States cartograms were seen first, the China cartograms second. The United States cartograms were always seen first so that the subjects might not be too intimidated or frustrated by starting out with the unfamiliar region. Also, by keeping the cartograms grouped by region subjects could maintain focus on one region at a time.

Three tests were used, where the order of cartograms within each region group varied according to format. In one test, the order was still-play-slider. In the second test, the order was play-still-slider. In the third test, the order was slider-still-play. In this way, any learning effect that might occur from seeing the earlier cartograms was spread evenly over the three formats for the test group as a whole.

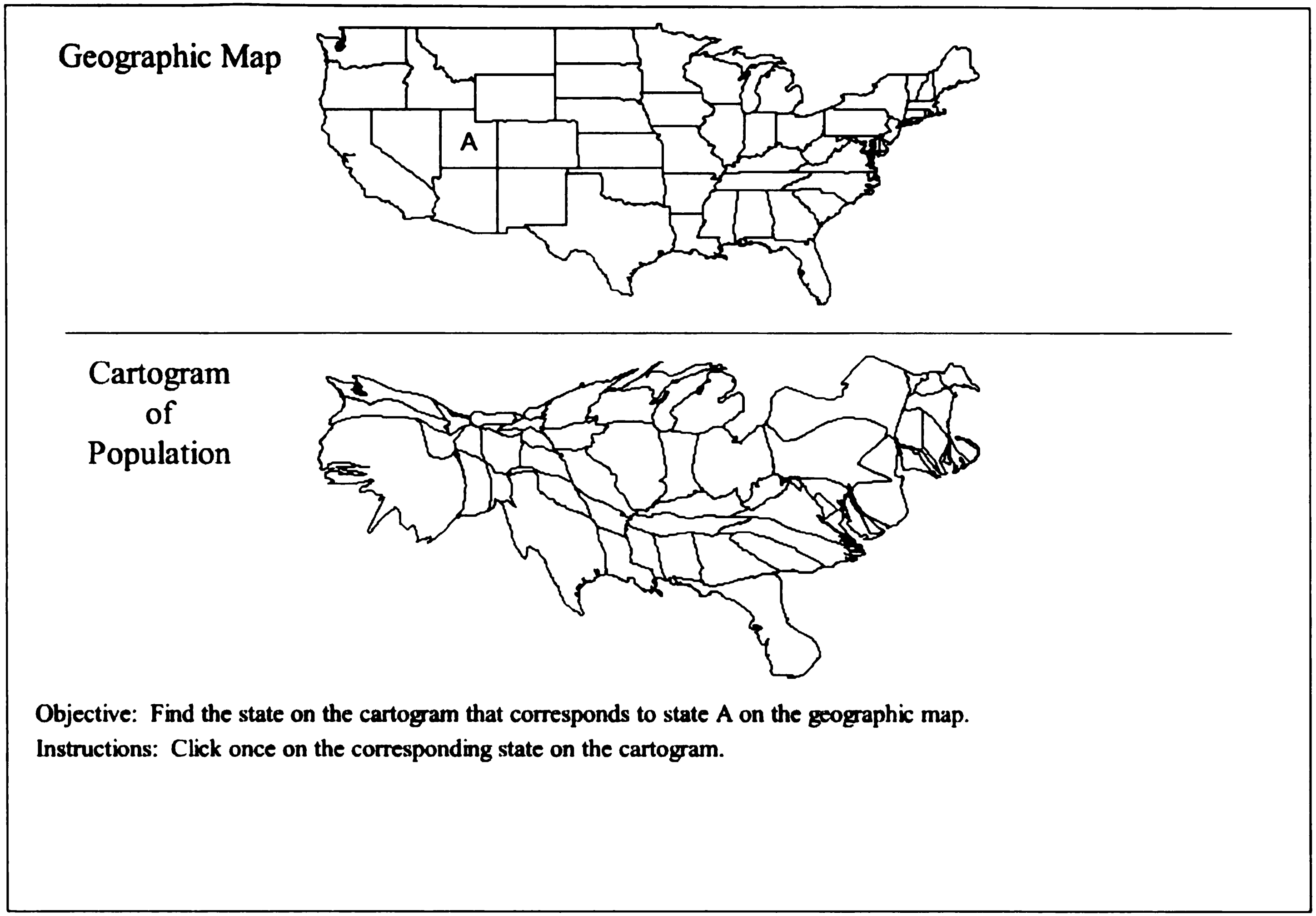


Figure 12. Still format.

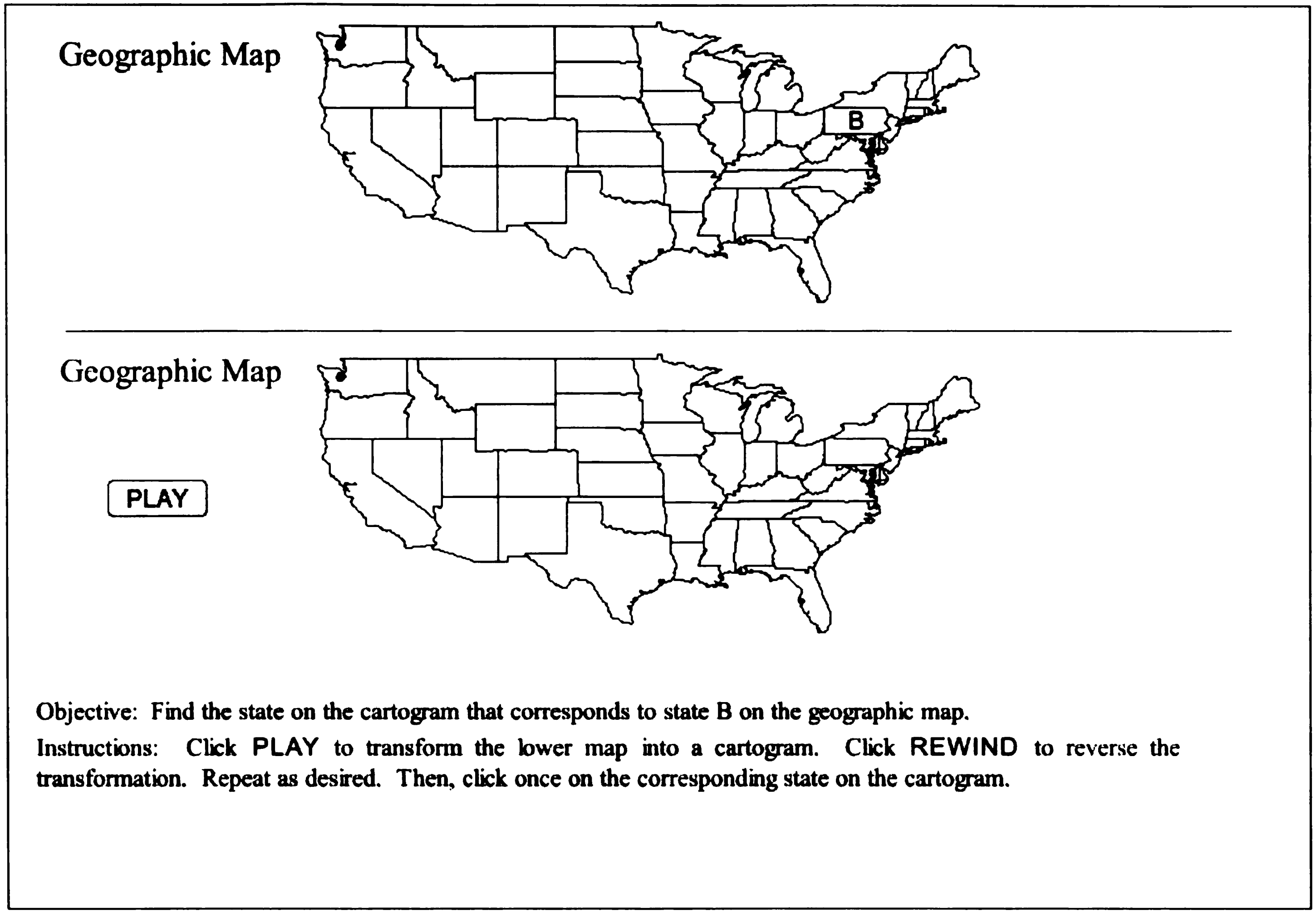


Figure 13. Play format (zero iterations).

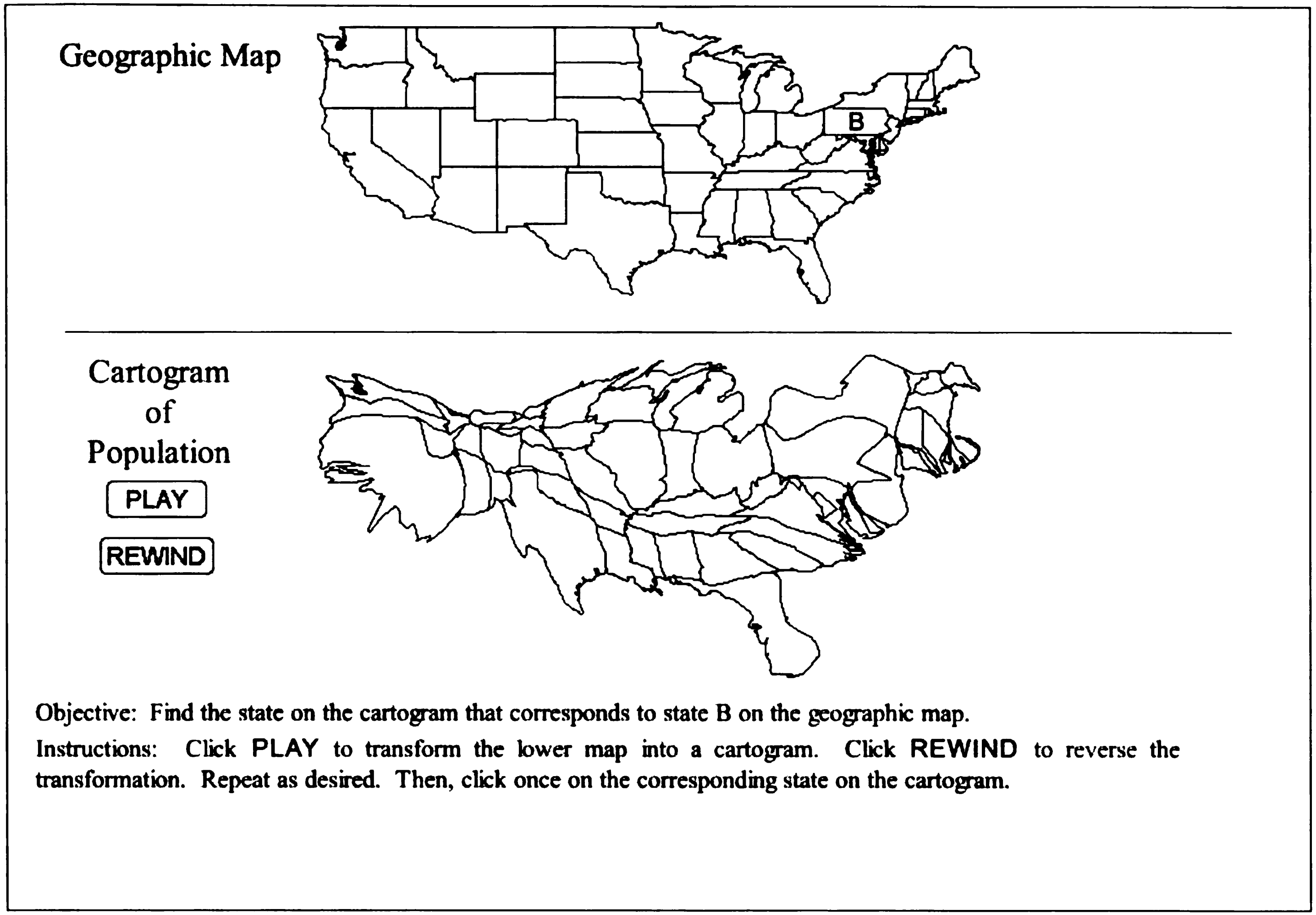


Figure 14. Play format (final iteration).

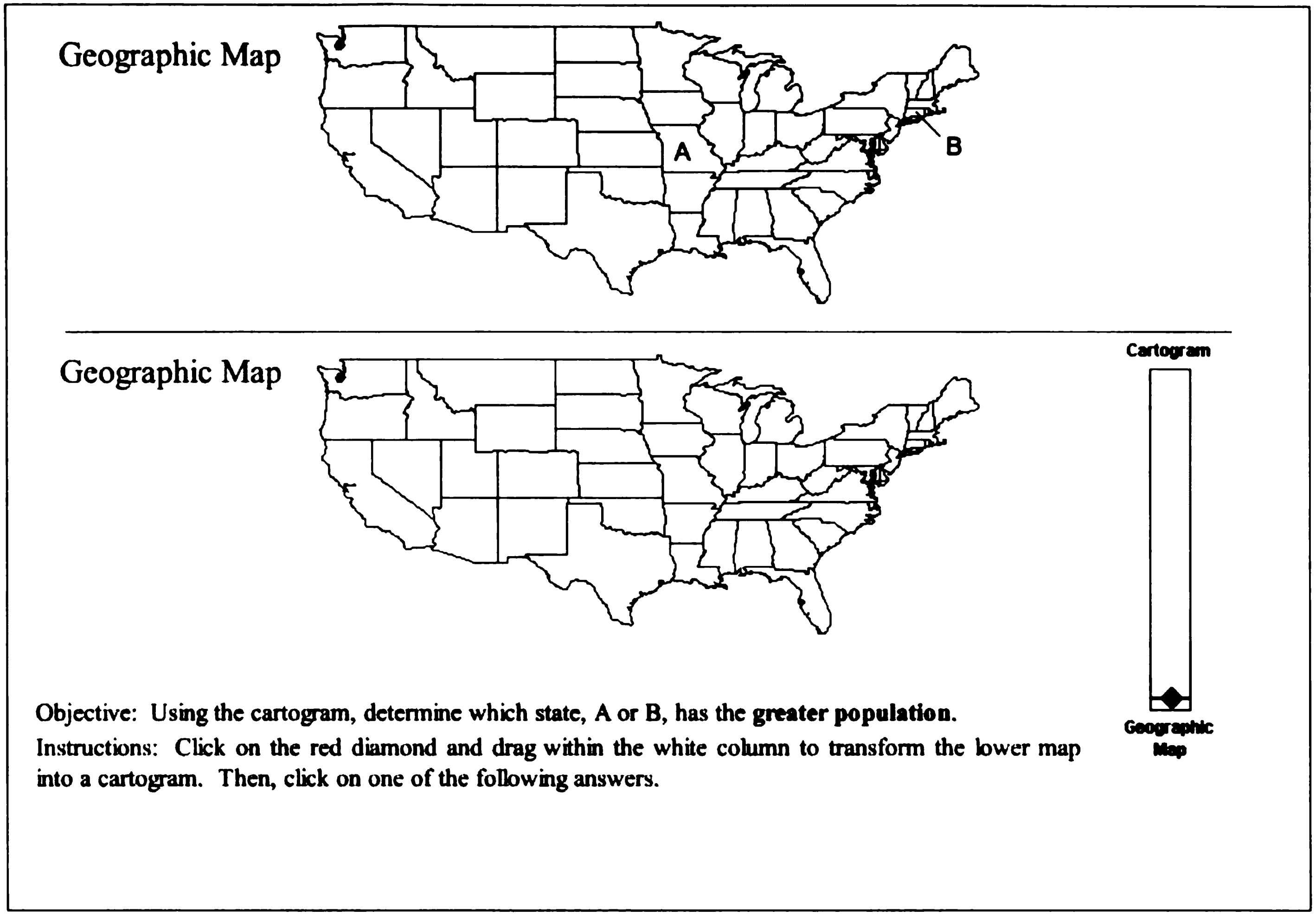


Figure 15. Slider format (zero iterations).

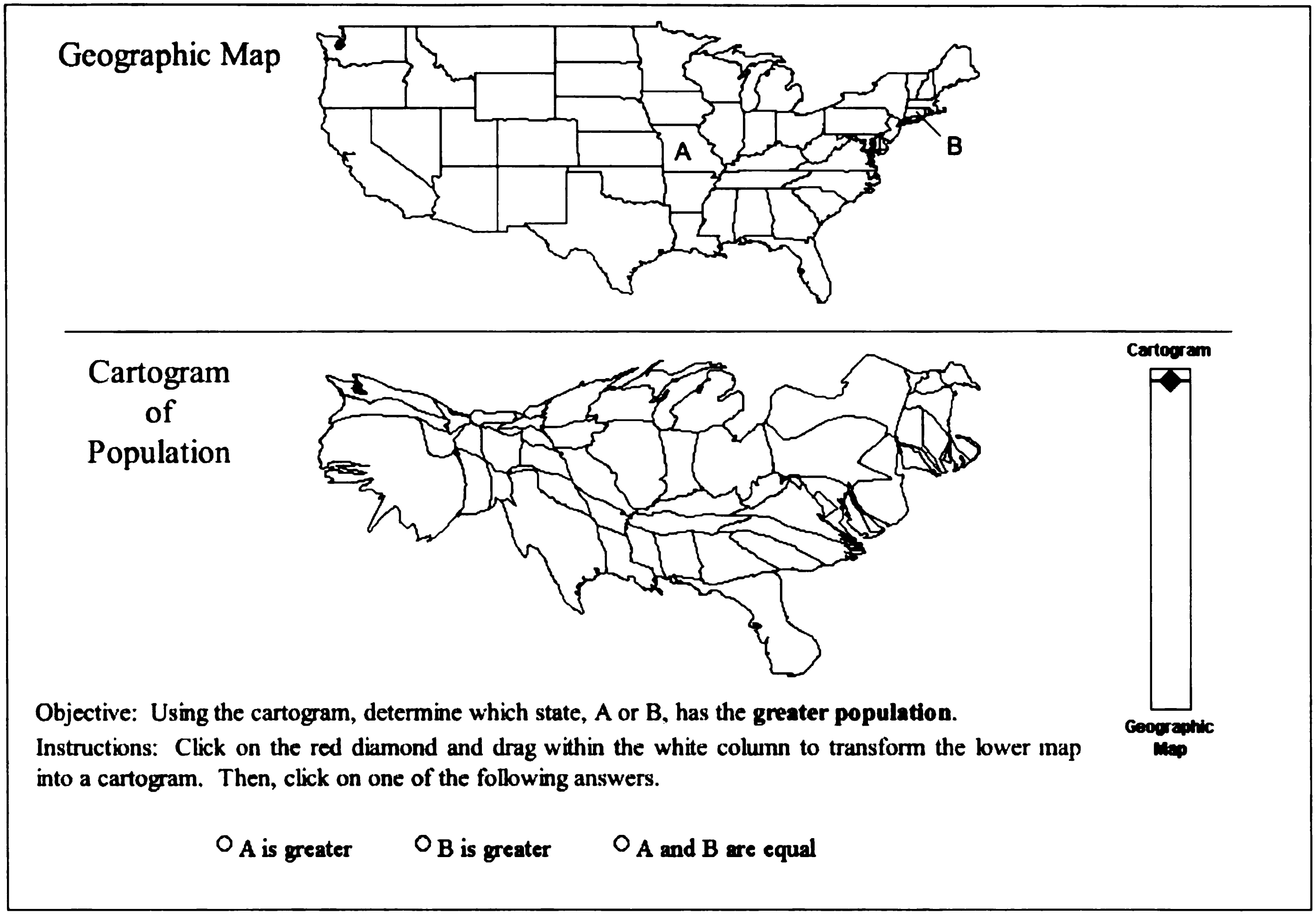


Figure 16. Slider format (final iteration).

Selecting the questions to ask

As stated in the literature review, Griffin's 1983 research discovered that two map transformation qualities were affecting the responses of the subjects: change in angular location of units and change in each unit's shape. Subjects were not adequately mentally performing the transformation between geographic space and cartogram space. The hypothesis of this research is that allowing the reader to view the transformation in an animation will alleviate this problem. Therefore, the test questions were designed to focus on the transformations that the animation might aid in understanding. With areas "A" and "B" labeled on the geographic map only, subjects performed three tasks with each cartogram:

1. Find the state/province on the cartogram that corresponds to state/province A on the geographic map.
2. Find the state/province on the cartogram that corresponds to state/province B on the geographic map.
3. Using the cartogram, determine which state/province, A or B, has the greater value.

The first two tasks were patterned after Griffin's experimental design. They directed the subject to locate a corresponding area on the cartogram, given a labeled area on the geographic base map **(Figures 12 and 14)**. Results of these tasks determined if the subject could understand the transformation and recognize the same area on the base map and the cartogram. The states and provinces chosen for the test were selected based on two criteria of change: each had a noticeable amount of shape distortion between the base map and the cartogram, and each moved angularly from its base map location.

The third task required the subject to compare sizes of the two areas on the cartogram and determine their rank order **(Figure 16)**. Results of this task determined how well the subject could interpret the data on the cartogram. Even if the subject incorrectly located A and/or B, a correct answer to the third question was still possible based on the relative sizes of the areas chosen for that task.

The correct responses to the third task were determined based on ranks of the data values of the areas. "Greater" areas differed by at least ten rank positions. The difference in size was easily discernible. To be considered "equal," areas had to be within two rank positions of each other.

To answer the questions implied in the first two tasks, the subject clicked on the corresponding area on the cartogram. For the third task, the subject clicked on one of three radio buttons: A is greater, B is greater, or A and B are equal. The still format displayed the cartogram in its final iteration only. The subject answered directly from that screen. The play and slider animation formats started off with the cartogram at zero iterations, and the subject had to first view the animated transformation at least once before being able to answer the questions. The ability to answer the questions by clicking on the map or the radio buttons was not activated until the final iteration was displayed.

The text of the cartogram test in its entirety can be found in Appendix B.

Scoring the test

The cartogram test program was designed to record a navigational log of the subject's movements through the program. The log also recorded the subject's answers to the test questions and the time spent on each question. The output was a text document.

Because of Macromedia Director's idiosyncrasies, the easiest way to record the subject's answers to the first two questions was to register the coordinate location of the mouse click on the screen. Further processing was needed after completion of the test to match each coordinate with a specific state or province. The time was recorded in Director's unit of measurement, the tick, or one-sixtieth of a second. The recorded times were divided by sixty to get the number of seconds.

One preliminary hypothesis of this research was that the response time for questions with animated cartograms would be shorter than that for questions with still cartograms. By the time the test program was completed, it had become clear that response time was actually likely to increase, given that the subject could play and replay the transformation again and again, taking more time than on a still format cartogram. Increased time had become the hypothesis, then; however, it was also predicted that subjects' perception of time might be reversed because viewing the transformation was expected to increase comprehension and lessen frustration. The subject may feel less time is taken on the animated cartograms than the still cartograms because the animated cartograms were understood with more ease, when in fact more time was taken by continually reviewing the animation.

The time was recorded from the instant a subject entered a question screen to the instant the subject exited the screen by answering the question. The measure included time spent viewing the basic screen layout, reading the questions, and performing animations. The average time spent on each question was compared to subjects' perceptions of time, and observations were made of several subjects while they were taking the test to see what behavior took place during the elapsed time.

Pretest and posttest questionnaires

Pretest and posttest questionnaires on paper **(Appendix C)** were developed in conjunction with the computerized cartogram test. The pretest questionnaire was designed to determine the depth and breadth of subjects' prior exposure to cartograms. In addition to answering questions, subjects were to sketch mental maps of the continental United States and China, determining if the United States was the more familiar region as presumed. Blades (1990) has shown that sketch maps are a reliable source of data about readers' mental representations of areas. The posttest questionnaire asked the subjects to evaluate their testing experience, the design and navigability of the program, and the three different presentation formats -- still, play animation and slider animation.

Testing procedure

Testing took place in a computer laboratory. Upon receipt of approval from the University Committee for Research Involving Human Subjects, recruitment of subjects commenced. Announcements were made in geography classes and volunteers were solicited from among geography graduate students. Fourteen test sessions were held over a two-week period. One to six subjects were tested in each session.

An oral overview of the testing procedure was given and a written consent form was obtained from each subject. The next step was the pretest questionnaire, taken with paper and pencil. The pretest was the most time-consuming part of the entire test, asking the subjects to construct the two mental maps. A guideline of twenty minutes was given for completing this step. However, the limit was flexible; as soon as all subjects in a particular session had indicated their completion of the pretest, they were all able to move on.

The subjects were then directed to individual computers on which the cartogram test program was installed. The test program was designed to be self-sufficient, running independently of the Director software and containing its own instructions. The researcher remained in the room for technical support but did not control any aspect of the test program itself. Subjects were allowed as much time as needed to complete the cartogram test. They were not told that the time spent on each question would be recorded.

As soon as individuals finished the cartogram test, they moved to the final step, the posttest questionnaire, again taken with paper and pencil. They were allowed as much time as needed to complete this step as well. At the completion of the three tests, subjects were paid five dollars as compensation for their participation.

Statistical methods

The experiment was planned as a factorial repeated measures design. There was one categorical independent variable or factor, REGION. REGION could be one of two categories: the familiar region or the unfamiliar region. The dependent variable was FORMAT. FORMAT had three levels: still, play or slider. Each subject's performance was repeatedly measured while varying the level of format. Since each subject was measured at every level, FORMAT was a within-subjects or repeated measures variable. REGION was used as a grouping variable.

A factorial repeated measures analysis of variance (ANOVA) test was used to assess three hypotheses (Wilkinson et al. 1996). The first hypothesis was that the familiar region and the unfamiliar region had different overall mean scores. The familiar region was expected to have higher overall mean scores. The unfamiliar region was expected to have lower mean scores.

The second hypothesis was that the different formats had different mean scores overall. The animated formats were expected to have higher mean scores than the still format. The third hypothesis of the ANOVA test was that the mean scores would be affected by the interaction between the format and the region. The animation was expected to have more of an effect on responses to the unfamiliar region.

Chapter 4

RESULTS

Description of subjects

All subjects were students at Michigan State University. A total of thirty-three subjects participated in the study. The navigational log file for one of the subjects was found to be corrupt for some unknown reason and could not be used. Thirty-two subjects, then, were used in the analysis. Of the thirty-two subjects, fourteen were male and eighteen were female. The ages ranged from nineteen to fifty-two, with a median age of twenty-two.

Subjects were asked to complete the paper-and-pencil pretest questionnaire in twenty minutes. Subjects generally took about fifteen to twenty minutes to finish. One subject took about twenty-five minutes.

Prior knowledge of cartograms

The first two questions on the pretest questionnaire **(Appendix C)** asked if the subject had ever heard of a map called a cartogram and if so, to provide a definition. Nineteen subjects of the thirty-two (59.4%) claimed to have heard of a cartogram, but only six subjects of the nineteen (18.8% of the total test pool of thirty-two) were able to provide an accurate definition. Eight of the nineteen gave an incorrect or vague definition, and five of the nineteen stated they did not know the definition. Thirteen subjects of the thirty-two (40.6%) had never heard of a cartogram.

The subjects were asked if they had ever seen a cartogram in any of a list of contexts. Twelve subjects of the thirty-two (37.5%) had never seen a cartogram. One of the subjects who had never heard of a cartogram did not answer this question, but it was assumed that having never heard of a cartogram, the subject had also never seen one. The answers of the thirteen subjects who claimed to have heard of a cartogram but were unable to provide an accurate definition were not tallied because the subjects were not able to prove sufficiently their ability to recognize a cartogram.

Of the six subjects who provided a correct definition, two had seen a cartogram in an atlas, five in a textbook, five in a classroom (used by a teacher as a visual aid), and three in a journal, newspaper or other printed media. One had seen a cartogram on the Internet, television or other electronic media, and one on a postcard.

The subjects were asked if they had ever used a cartogram in any of a list of contexts. Nineteen subjects of the thirty-two (59.4%) had never used one. Of the remaining thirteen subjects, seven were in the group unable to provide an accurate definition. Again, their answers were not tallied. Of the six subjects who had provided a correct definition of a cartogram, three had used a cartogram in a classroom exercise or lesson and four had used a cartogram to answer a test question. Two had used a cartogram for their own personal reference. No subjects had included someone else's cartogram in a paper or project, and no subjects had created their own.

Familiarity with each region

To assess whether the United States was the familiar region and China the unfamiliar region as presumed, subjects were asked to draw and label as many individual states or provinces as they could using only their memory **(Appendix D)**. Correct shape and location of states or provinces was not evaluated; only the total number of labeled ones.

Twenty-eight subjects out of thirty-two (87.5%) were able to identify at least half of the forty-nine continental United States (forty-eight states and the District of Columbia). Eighteen subjects (56.3%) were able to identify over forty states, and no one identified fewer than eleven states. Two subjects out of thirty-two (6.3%) were able to identify at least half of China's thirty provinces. Out of the remaining thirty subjects (93.8%), no one was able to identify more than two provinces. Five of the thirty identified Tibet and five of the thirty identified Mongolia as provinces of China. Twenty-seven at least attempted to draw an outline of the country. Two subjects left the area completely blank.

These results indicated that every subject was familiar with the United States, but not everyone was unfamiliar with China. Both the U.S. and China were familiar to two subjects.

Practice materials

The introductory part of the cartogram test program first defined a cartogram, then displayed an example using a cartogram of the number of births in New England. This example cartogram was used throughout the introduction. Subjects were next given a multiple-choice question to see if they then clearly understood the definition of a cartogram. Thirty-one subjects of the thirty-two (96.9%) selected the correct definition. The subject selecting the wrong definition chose the correct response on the second try.

The introduction displayed the two formats of animation, automatic and manual, and subjects were asked to familiarize themselves with both formats. Finally, the introduction explained the basics of the test and displayed three examples of test questions identical to those on the test. Though the actual test questions appeared in all three formats, the example questions portrayed the example cartogram in still format only.

Results from the introductory part of the test showed that subjects were able to familiarize themselves with the test format and complete the tasks as instructed with little difficulty.

Processing the test scores

The raw results of the cartogram test were tallied in tabular form. The table lists each question by variable and format, then gives the number of subjects who gave a correct answer to that question and the average time taken to answer for both regions **(Table 4)**.

Upon examination of the raw results, an error in the testing method was found. The answers to the third task, comparing the sizes of areas A and B, had been determined by the differences in rank of the data value of the areas. Ideally, the sizes of the areas on the cartogram maintain these rankings. However, due to varying forces of distortion the enumeration unit may not end up with its area corresponding exactly to its data value. Ranking the areas according to actual cartogram area instead of data value resulted in slightly different rankings for some of the areas **(Table 5)**.

Table 4. Raw results of cartogram test.

Variable	Format	Question	U.S. Correct	Avg Time (seconds)	China Correct	Avg Time (seconds)
Population	Still	Locate A	30/32	24.412	23/32	26.119
		Locate B	32/32	12.108	22/32	27.537
		Compare	7/32	28.784	28/32	14.741
	Play	Locate A	32/32	36.230	32/32	18.402
		Locate B	32/32	17.077	32/32	13.328
		Compare	32/32	26.059	32/32	14.613
	Slider	Locate A	31/32	36.602	32/32	15.492
		Locate B	31/32	23.996	32/32	10.391
		Compare	29/32	33.077	20/32	23.298
Cattle	Still	Locate A	29/32	11.411	32/32	9.596
		Locate B	32/32	7.232	31/32	12.034
		Compare	31/32	15.057	32/32	6.446
	Play	Locate A	32/32	17.750	32/32	10.780
		Locate B	32/32	9.808	32/32	11.882
		Compare	31/32	22.246	25/32	27.757
	Slider	Locate A	32/32	16.801	32/32	13.928
		Locate B	32/32	10.873	32/32	10.538
		Compare	20/32	30.449	32/32	17.914

Table 5. Rank and percentage differences for areas A and B.
Bold indicates questions where changed ranks no longer met criteria.

Region	Variable	Format	Area Name	Data Rank	Cartogram Area Rank	Percent Difference
U.S.	Population	Still	Utah	36	**39**	46.11%
			Arkansas	34	**34**	
		Play	Kansas	33	31	80.55%
			Pennsylvania	5	4	
		Slider	Missouri	15	13	54.28%
			Connecticut	27	32	
	Cattle	Still	Indiana	30	31	55.01%
			Wyoming	17	17	
		Play	Kentucky	8	8	67.84%
			Nevada	33	32	
		Slider	Colorado	12	**10**	3.78%
			Tennessee	10	**13**	

Table 5 (cont'd).
Bold indicates questions where changed ranks no longer met criteria.

Region	Variable	Format	Area Name	Data Rank	Cartogram Area Rank	Percent Difference
China	Population	Still	Sichuan	1	1	69.94%
			Shanxi	19	19	
		Play	Qinghai	29	29	92.12%
			Hunan	7	6	
		Slider	Yunnan	14	**10**	14.70%
			Jiangxi	13	**14**	
	Cattle	Still	Fujian	25	25	94.18%
			Henan	1	1	
		Play	Gansu	12	**10**	43.63%
			Hubei	22	**18**	
		Slider	Shaanxi	18	19	68.54%
			Anhui	3	4	

When using the new rankings, the previously established criteria for "greater" and "equal" were preserved for all but four of the twelve comparison questions. Three of these comparison questions had an original answer of "equal" and one had an original answer of "A is greater."

The areas involved in the "A is greater" question (China/Cattle/Play), when assigned the new ranks, only differed by eight rank-positions instead of ten. The areas were becoming too close in rank and actual size for one to be considered greater. When the areas in the three "equal" questions were assigned the new ranks, two of the questions' areas differed by three rank-positions and one differed by five rank-positions. Too much difference existed for the areas to be considered equal in these three questions.

Comparing the percent size differences of each pair of areas confirmed these figures **(Table 5)**, especially for one of the "equal" questions. The areas were too close in percent size difference (only 3.76% different) to expect subjects to discern any difference between them. For this question (U.S./Cattle/Slider), all three answers (A is greater, B is greater, A and B are equal) had to be accepted. Subjects' answers to the four affected questions were rescored. The adjusted answers are reflected in the text of the test **(Appendix B)**.

Another adjustment to the scores was made based on familiarity with the two regions. Two subjects evidenced enough familiarity with China that it was *not* an unfamiliar region to them. Therefore, their scores for the questions using cartograms of China were considered "familiar region" scores. Instead of naming the regions the United States and China in the scoring, the regions were instead called "Familiar" and "Unfamiliar." The total number of answers for the familiar region became 34 and the total for the unfamiliar region became 30. The adjusted results of the cartogram test were tallied in tabular form **(Table 6)**.

Main results

Once the tests were rescored, statistical testing could be performed. During the cartogram test, different subjects viewed the twelve cartograms in different format orders. Nine subjects saw the cartograms in still-play-slider order, eleven in play-still-slider order, and twelve in slider-still-play order. Although it would have taken equal numbers of subjects viewing all six possible orders to completely balance the design, these selected orders did prevent any one format from being consistently first or last. Since approximately equal numbers of subjects saw the cartograms in each of the three orders, any learning effects

Table 6. Adjusted results of cartogram test.

Variable	Format	Question	Familiar Correct	Avg Time (seconds)	Unfamiliar Correct	Avg Time (seconds)
Population	Still	Locate A	34/34	24.412	21/30	26.119
		Locate B	33/34	12.108	21/30	27.537
		Compare	33/34	28.784	26/30	14.741
	Play	Locate A	34/34	36.230	30/30	18.402
		Locate B	34/34	17.077	30/30	13.328
		Compare	34/34	26.059	30/30	14.613
	Slider	Locate A	34/34	36.602	30/30	15.492
		Locate B	33/34	23.996	30/30	10.391
		Compare	30/34	33.077	28/30	23.298
Cattle	Still	Locate A	31/34	11.411	30/30	9.596
		Locate B	34/34	7.232	29/30	12.034
		Compare	33/34	15.057	30/30	6.446
	Play	Locate A	34/34	17.750	30/30	10.780
		Locate B	34/34	9.808	30/30	11.882
		Compare	33/34	22.246	28/30	27.757
	Slider	Locate A	34/34	16.801	30/30	13.928
		Locate B	34/34	10.873	30/30	10.538
		Compare	27/34	30.449	30/30	17.914

caused by the earlier displays were assumed to be evenly distributed over the three formats.

Though some test sessions contained multiple people, each subject took the test independently from every other subject. To make the assumption that mean values in samples are normally distributed, the sample size should generally be at least thirty. This experiment had a subject sample size of thirty-two, and with multiple questions, sample size in statistical tests became larger. With independence and normality assumptions met, a parametric statistical procedure could be used. A significance level of 0.05 was selected for all tests.

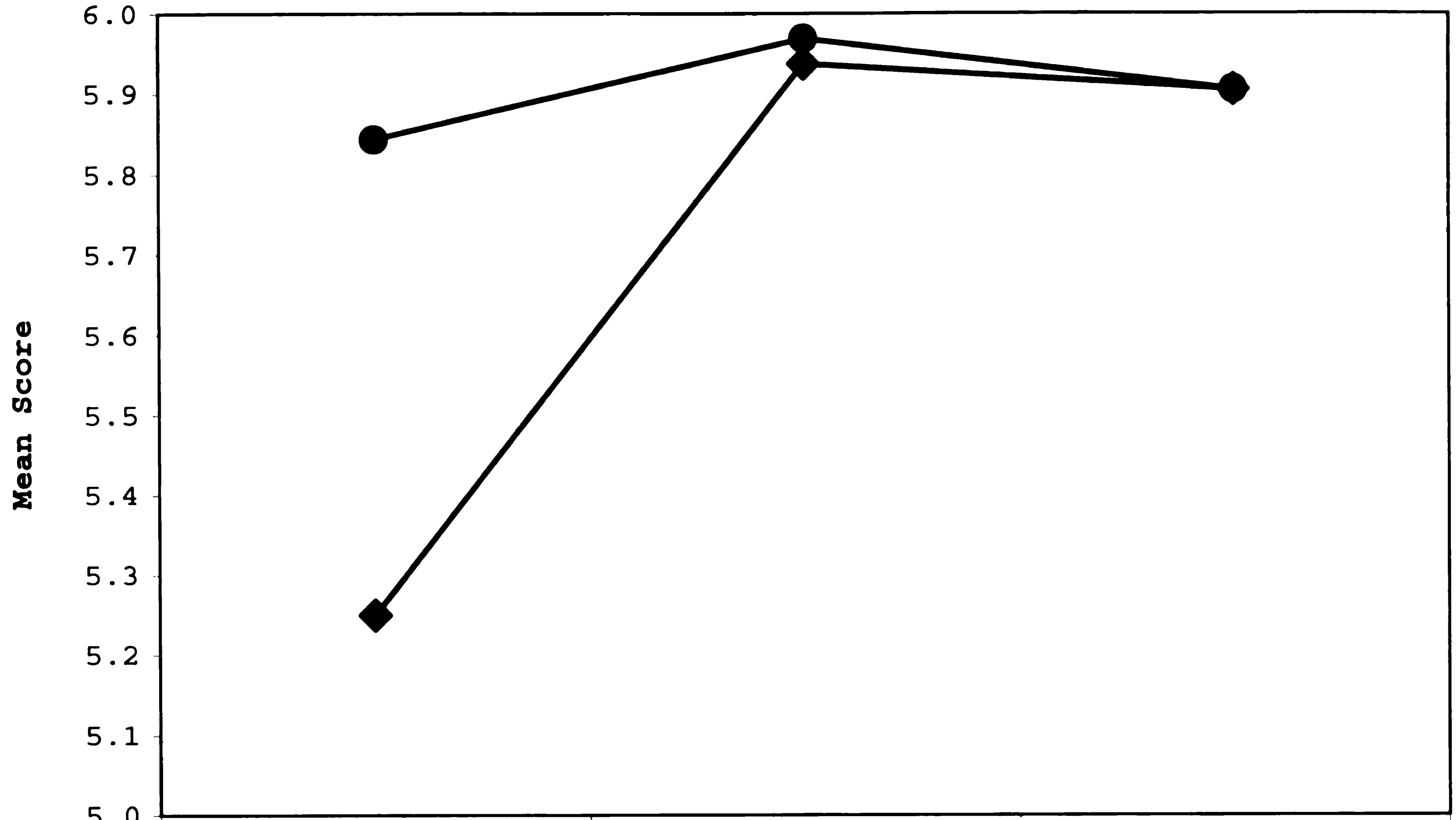
All statistical analysis was performed using the program SYSTAT. A factorial repeated measures ANOVA test was performed on the data. ANOVA is based on the F statistic. The first question, called the "Familiarity" question **(Table 7)**, was whether the overall mean scores of the familiar and unfamiliar regions were significantly different when controlling for format. The null hypothesis was that the mean scores were equal. The alternative hypothesis was that the means for the familiar and unfamiliar regions were not equal. The calculated F statistic, 7.792, was greater than the rejection statistic of 4.000 with 1 and 60 degrees of freedom. The null hypothesis was rejected; there was at least one significant

Table 7. Repeated measures ANOVA results.

Question	Confidence level	F statistic	Probability
Familiarity	0.05	7.792	0.007
Format	0.05	22.933	0.000
Familiarity x Format (interaction)	0.05	9.009	0.000

difference in scores between the two types of regions. When looking at the mean scores for each region in each format **(Figure 17)**, the greatest contrast is in the scores of the still formats.

The second question, called the "Format" question **(Table 7)**, was whether the three formats had significantly different mean scores. The null hypothesis was that the mean scores for the different formats were equal. The alternative hypothesis was that the mean scores were not equal. The calculated F statistic, 22.933, was greater than the rejection statistic of 3.150 with 2 and 60 degrees of freedom. The null hypothesis was rejected. At least one significant difference existed between the mean scores for the three different formats when controlling for familiarity of region. A visual comparison of the mean scores **(Figure 17)** showed that for both regions, the play format had the highest mean scores, the slider format had the next highest



	Still	Play	Slider
Familiar	5.844	5.969	5.906
Unfamiliar	5.250	5.938	5.906

Format

Figure 17. Mean Scores.

scores (very close to those for the play format), and the still format (especially for the unfamiliar region) had the lowest mean scores.

The third question of the ANOVA test, called the "Familiarity x Format" or "interaction" question **(Table 7)**, was whether the format had a different effect on mean scores for the familiar vs. unfamiliar region. The null hypothesis was that there was no interaction. The alternative hypothesis was that there was an interaction. The calculated F statistic, 9.009, was greater than the rejection statistic of 3.150 with 2 and 60 degrees of freedom. The null hypothesis was rejected; a significant interaction effect existed between the regions and formats. Looking at the mean scores **(Figure 17)**, the greater improvement was in the mean scores for the unfamiliar region. The still format had a much lower score than either animation format. In contrast, the scores for the familiar region are relatively consistent over the three formats.

Posttest questionnaire results

The paper-and-pencil posttest questionnaire **(Appendix C)** asked subjects to evaluate several aspects of the testing experience. Subjects were given as much time as needed to complete the posttest but generally finished in about ten minutes. The results, minus subjects' comments in their own words, were recorded in tabular form **(Table 8)**.

First, several questions were asked about the computerized testing. Six subjects of the thirty-two (18.8%) had taken a computerized test like the cartogram test before. Twenty-six subjects (81.3%) had not. Twenty-nine subjects of the thirty-two (90.6%) felt comfortable using the computer to take the test. Three subjects (9.4%) felt neutral and no subjects felt uncomfortable.

A series of questions was asked about the design of the cartogram test program. Twenty-nine subjects of the thirty-two (90.6%) felt the introduction adequately prepared them to take the test. Three subjects (9.4%) felt neutral and no subjects felt the introduction did not adequately prepare them.

Thirty-one subjects of the thirty-two (96.9%) felt the definition of a cartogram was helpful. One subject (3.1%) was neutral. This subject commented that it would have been useful to see the definition again during the test, or to receive an explanation before the test of why cartograms are needed. No subjects felt the definition of a cartogram was unhelpful.

Table 8. Numerical results of posttest.

Question	Yes	Neutral	No	Still	Play	Slider
Had you ever taken a computerized test like this before?	6	N/A	26			
Did you feel comfortable using the computer to take the test?	29	3	0			
Did you feel the introduction adequately prepared you to take the test?	29	3	0			
Was the definition of a cartogram helpful?	31	1	0			
Were the examples of the different formats helpful?	30	2	0			
Were the examples of the test questions helpful?	28	4	0			
Was it easy to navigate through the testing program?	31	1	0			
Which format did you find easiest and fastest to use to locate areas A and B?				0	11	22
Which format did you find easiest and fastest to use to compare the sizes of A and B?				4	9	19
Do you think that cartograms could be a useful tool for presenting spatial information?	26	5	1			

Thirty subjects of the thirty-two (93.8%) felt the format examples of the automatic animation and the manual animation were helpful. Two subjects (6.3%) felt neutral and no subjects felt the format examples were unhelpful.

Twenty-eight subjects of the thirty-two (87.5%) felt the test question examples were helpful. Four subjects (12.5%) felt neutral and no subjects felt the test question examples were unhelpful.

Thirty-one subjects of the thirty-two (96.9%) felt it was easy to navigate through the testing program. One subject (3.1%) felt neutral and no subject felt the program was "not easy" to navigate.

The posttest questionnaire then asked which format (still, play or slider) was easiest and fastest to use to locate areas A and B. No subjects preferred the still format. Eleven subjects of the thirty-two (34.4%) preferred the play format, and twenty-two subjects (68.8%) preferred the slider format. The total does not add up to thirty-two because one subject chose both the play and slider formats.

Three subjects made specific mention of the fact that the static format was difficult to use with China because of their unfamiliarity with China's geography. The most prevalent comment of those who preferred the play format was that they did not have to concentrate on moving the slider; they could simply press one button and sit back to watch the animation. Several subjects also noted that since the mouse cursor was not in use during the transformation, it could be used as a pointer to mark the position of the changing state or province on the map or cartogram. Subjects who preferred the slider format generally made some mention of the fact that this format allowed them to control the speed of the transformation.

The posttest questionnaire also asked which format (still, play or slider) was easiest and fastest to use to compare the areas of A and B. Four subjects of the thirty-two (12.5%) preferred the still format. Nine subjects (28.1%) preferred the play format, and nineteen subjects (59.4%) preferred the slider format.

The four subjects who preferred the static format felt that movement was not needed to compare sizes of areas. The other subjects, no matter their preference for automatic (play) or manual (slider) animation, gave generally the same reasons for their preferences as they did in the previous question.

Though a majority of subjects felt that the play and slider presentation formats were easiest and fastest to use, looking at overall average response times **(Table 9)** shows that, as expected, subjects spent more time on these formats than on the still format. The average time spent on all still questions was 16.282 seconds, the average on all play questions was 19.788 seconds, and the average on all slider questions was 21.756 seconds.

Table 9. Average times.

Format	Average time (seconds)
Still	16.282
Play	19.788
Slider	21.756

The final question on the posttest questionnaire asked if the subject believed the cartogram could be a useful tool for presenting spatial information. Twenty-six subjects of the thirty-two (81.3%) answered yes. Five subjects (15.6%) were neutral. One subject (3.1%) answered no and commented that cartograms "could confuse learners of spatial relations."

One subject who answered that cartograms could be useful then went on to say that "I have a hard time with 'spatial comparisons'" but cartograms might work well for others. Several subjects mentioned that they were visual learners and that cartograms would be an ideal learning tool for them. One subject wrote that cartograms "allow for information to be presented with regard to data representation rather than geographic boundaries."

Subjects who felt neutral about the usefulness of cartograms commented that without a detailed explanation, cartograms could be difficult to interpret. Some stated that their ambivalence came from the presentation format; cartograms might be useful in an animated environment, but "static environments can prove very challenging [when one is faced with] unfamiliar areas."

Subjects were given the opportunity to make any comments they wished at the end of the posttest. The prevailing response was that the cartogram test program was fun and interesting and a good introduction to cartograms. Overall subjects appeared to have a positive testing experience.

Chapter 5

DISCUSSION

The subjects and their previous knowledge

The sample population, all college students, was relatively homogeneous. Although a greater variety of previous experiences with cartograms might have turned out with a broader sample, the limitations seemed justified, since college students are among those to whom a cartogram might be useful. About equal numbers of males and females took part, which means that skewing of the results due to possible gender bias was unlikely.

The pretest questionnaire revealed that cartograms are not well known to this population. Though over half the subjects claimed to have heard of a cartogram, only about one fifth could provide an accurate definition. A majority of subjects reported having heard the word "cartogram" before, but were unable to define it. Quite possibly, most of the subjects would have been able to recognize a cartogram if shown one. The pretest question was evaluating mental understanding of a cartogram, not looking for simple visual recognition.

Though only a small number of subjects were able to describe a cartogram accurately, the most common places cartograms were seen were in educational settings, either textbooks or classrooms. They were not often seen in printed and electronic media. Since all subjects were college students, the most likely place they would see cartograms would be an educational setting. However, some subjects were significantly older than the median age of twenty-two and had more life experience; these subjects may have had more opportunity to see cartograms in other contexts. Perusal of the pretests proved this to be false, but the population of "older" subjects was relatively small in this experiment. A wider sample of "older" subjects may have a different result.

The majority of the subjects had never used a cartogram. Of the subjects who were able to correctly define a cartogram, the most common uses were to answer a test question or to support a classroom lesson; again, educational settings were involved. Not surprisingly, no subject had ever used a cartogram in a paper or project, and no subject had ever created one.

The United States was shown to be a familiar region to most of the subjects. Most could identify at least half of the states, and no one identified fewer than eleven. Likewise, China was shown to be an unfamiliar region to most subjects, but two were able to identify at least half of China's provinces. These two subjects were also able to construct sufficient mental maps of the United States, so the United States was not an unfamiliar region; instead, both regions were familiar. The mental map task prevented the assumption that the United States was the familiar region and China the unfamiliar region for everyone. The regions could be appropriately categorized as familiar or unfamiliar for each individual subject. Without having subjects sketch mental maps as a check on this assumption, an error could easily have been made. This result is a clear indication that familiarity assumptions should be checked in any cartographic testing where it might have an influence.

Even though the familiarity was readily classified, the quality of familiar-area mental maps varied widely. Some subjects were able to recreate shape, location and identity; others only location and identity, drawing simple rectangles instead of correct shapes. A few subjects did not attempt to draw any sort of shape and simply wrote in state names in the approximate locations. All subjects first drew outlines of the countries and then attempted to fill in the individual states or provinces, instead of drawing the states and provinces first to create the outlines of the countries. This response probably results from greater familiarity with country outlines than with their internal subdivisions. Subjects have probably seen the United States and China both with and without their respective subdivisions, but are more likely to remember "wholes" than "parts."

Expected results vs. statistical results

The purpose of the research was to determine if the addition of animation to cartograms improved the cartogram's ability to communicate, especially when the region was unfamiliar. This idea was definitely supported by the statistical tests.

Familiarity was shown to be a strong factor in communication when the cartograms were shown in the still format. This conclusion is already part of the general literature on cartograms, often worded as a caution to the cartographer not to use cartograms unless the depicted region is familiar to the audience. It is often impossible to test an audience's familiarity level with a selected region before creating the cartogram. Since cartograms have been seen only in a still environment for nearly all of their existence, the familiarity factor has hindered the use of cartograms.

While the greatest contrast occurred between the still format scores, the animated format scores for the two regions were extremely close. Familiarity with the region ceased to be a factor in both animated formats. Animated cartograms may be used to depict a greater range of geographic areas, then, since the audience's familiarity with the region is no longer a major concern.

Format was also shown to be a strong influence on communication, but it is apparent once again that the still format with the unfamiliar region is the one that differs from the rest. The graph of the scores shows that overall the play format had the highest mean scores and the still format the lowest. The slider format's mean scores fell in the middle, but were much closer to the scores for the play format.

The expected outcome was that slider would be the best format, and this was supported by subjects' two-to-one preference for the slider format on all types of questions. Subjects chose the slider format as easier and faster to use, so presumably the slider format would produce the highest scores as well. However, the numerical results showed the play format as having slightly higher scores.

Still, the difference in mean scores between the two animated formats was not large enough to advocate use of one method over the other. Both methods of animation achieved higher scores than the still format, especially for the unfamiliar region. Animation increased the effectiveness of the cartogram's ability to communicate, and the animated versions were preferred. With the wide range of familiarity even for the "familiar" area, the results provide a strong case for the use of animation with cartograms of any region, "familiar" or "unfamiliar."

Finally, a significant interaction effect existed between the two regions and the three formats, and the graph clearly indicated that the greatest improvement with animation came with the unfamiliar region. The mean scores for the unfamiliar region across formats differed much more than the mean scores for the familiar region. As expected, the cartogram's ability to communicate was most affected by animation when an unfamiliar region was depicted, and animation opens the door to effective cartogram communication for any region.

Subjects' posttest questionnaire responses

Readers' perceptions of time and effort should be taken into consideration when creating any kind of map. Readers are not likely to opt for a map perceived to be difficult or frustrating when a less difficult or less frustrating one is available.

Subjects displayed a clear preference for the animated formats over the still format. In their comments, they recognized the benefits of adding animation to cartograms, and even stated that cartograms might not be useful *unless* animation is used. They also preferred the slider format, as it gave them both the ability to view the transformation and control its speed and direction.

Though subjects felt that the play and slider formats were the "easiest and fastest" to use to answer both types of questions, they spent on average up to five seconds more on questions with these formats than with the still format. The increased time was probably a result of replaying the animation multiple times. Though the actual time spent on animated cartograms was longer than that spent on still cartograms, subjects' awareness of the time spent was apparently shorter. In all likelihood, the level of concentration necessary was also lessened with the animated maps. Combining "easiest" and "fastest" in the question may have confused the issue somewhat, but it seems unlikely that separating the ease and time components would have resulted in different preferences.

The majority of subjects had never taken a computerized test like the cartogram test before, but there was no fear of the computer or uncertainty about the tasks. Most subjects felt comfortable taking the test on the computer; no one felt uncomfortable. The test was easy to take and the tasks clearly defined. Whatever faults the test may have had, lack of comfort and clarity for subjects was not among them.

Weaknesses of the research

A major weakness of this experiment was the problem with the ranking of the areas. The choices of areas in the comparison questions were selected based on the ranked data values. The areas produced by the cartogram do not always conform to these rankings due to varying forces of distortion. Depending on the distribution, one pair of neighboring ranks might have very dissimilar values while another pair of widely separated ranks might be close in value. Even more important with the maps used here, the rankings as produced by the cartogram areas differed from the data value ranks. The answers to the comparison question should have been determined using the actual cartogram area rankings instead of the data value rankings. Unfortunately, this was discovered after the testing had already taken place, and adjustment of scores was necessary. The experimental design could have been stronger had the problem been anticipated and more appropriate pairs of areas been chosen.

The selection of enumeration units to be areas A and B was a difficult one in any case. Criteria such as visible distortion and angular movement from the original location were used to select areas, but each cartogram provided a multitude of possible choices that met these criteria. The researcher then subjectively selected from these possibilities. Had different areas been chosen, different results could conceivably have occurred, although it is unlikely that the overall conclusions would have changed.

Another improvement on the design of this experiment would be to have more test questions for each presentation format. This design used six questions for each combination of region and format for a total of thirty-six questions. The mean scores for the different formats are all fairly close. By themselves they do not appear to have much variance, even though the ANOVA test showed significant differences because of poor performance with the unfamiliar region in still format. A greater number of questions, varying in difficulty, would allow for more variation in the mean scores, and possibly a more visible difference.

An interesting observation about cartograms, still or animated, is that different methods of construction will produce different-looking cartograms from the same data. Different-looking cartograms may send different messages, even if they are displaying the same data. Identical tests using cartograms created from the same data as these cartograms, but constructed using different computer algorithms, would contribute to knowledge of those algorithms' accuracy and effectiveness as well as strengthen or modify the conclusions reached here. The results from this experiment must be tempered with the realization that they are based on cartograms produced with this particular method of cartogram construction.

No analysis was done specific to the type of task (location and comparison) being performed with the cartograms because the total number of questions for each region/format/task combination was so small (only six questions total, four location and two comparison). Again, a greater number of questions would allow for task-specific analysis. However, subjects were asked which format they preferred for each task. That subjects overwhelmingly chose the animated formats for both tasks was not surprising. Interestingly, while no subjects preferred the still format for the location tasks, four subjects preferred it for the comparison tasks. It may be that the format used to present cartograms should be task-specific. Depending on the purpose of the cartogram, perhaps animation may or may not be necessary.

Due to time limitations and the necessity of eliminating one subject, only thirty-two subjects were included in the analysis. A larger number of subjects would be more representative of the population. Also, a wider range of people could be tested. All subjects in this experiment were college students. Future research could widen the recruitment scope to children, older adults, and non-college students. It is suspected that testing subjects from outside an educational setting may produce different results, if only in the pretest questions dealing with exposure to cartograms.

Broader implications

Research with animated maps has had mixed conclusions, partly because of the many conditions under which animation is used. Though statistical analyses are often equivocal, subjects usually prefer animation to traditional, static methods of presenting maps. Partly attributed to the "novelty" effect, subject interest and motivation cannot be discounted when assessing animation's influence. Cartograms themselves are novel approaches to data representation; animated cartograms would seem to be doubling the novelty effect, which may be adding to the animation's effectiveness.

Though animation is generally used in cartography to represent temporal change, animation was used in this case to represent a kind of spatial change. The three tasks subjects were asked to accomplish focused on the spatial transformations taking place in the maps. The way in which animation was used and the purpose for which the maps were used were directly connected. Another task often used with cartograms is retrieval of quantitative data by estimating the sizes of areas. This task requires a legend to which the reader can compare sizes of areas on the map, and the question arises of whether to incorporate a static legend into an animated map. This dilemma exists not only for cartograms but for other types of animated maps as well. Perhaps animated legends are the answer, but the issue then becomes how to design such legends and test their effectiveness.

Now that animation has shown its effectiveness in one dimension, that of spatial change, perhaps it can be useful in two dimensions, combining spatial and temporal change. A series of cartograms could depict an attribute over time. Animation would allow the cartograms to morph either into the geographic base map or into the next time-sequential cartogram. Results from this research suggest that such animated sequences should be effective, but sound testing should be used to provide a concrete answer.

Chapter 6

SUMMARY AND CONCLUSIONS

The purpose of this research was to determine if the addition of animation to cartograms would increase the effectiveness of the cartogram's communication, especially with unfamiliar regions. A cartogram test was designed to present cartograms of a familiar region, the United States, and an unfamiliar region, China, in three formats. The three formats were still, having no movement; automatic animation through the use of a play button; and manual animation through the use of a slider bar.

A test pool of thirty-two subjects was recruited from the student population at Michigan State University. Subjects were tested in groups of one to six; each subject took the test independently and was paid five dollars as an incentive to participate.

Pretest questionnaire results showed that very few subjects were able to provide an accurate definition of a cartogram. Familiarity with cartograms was very low. Cartograms were most often seen and used in an educational setting. Subjects' mental maps indicated that the United States could be considered the familiar region and China the unfamiliar region for the majority of subjects, but two subjects showed familiarity with both countries.

Results of the cartogram test showed that there was a difference in accuracy between the familiar region and the unfamiliar region. A look at the graph of all mean scores shows that the greatest difference is between the mean scores for the still format. Familiarity with the region was very important with the still format questions. There was a significant difference in mean scores between the three formats as well, again because scores were so much lower for the unfamiliar region in still format. Finally, there was a significant interaction effect between familiarity and format. The greatest improvement was found in the difference between the mean scores for the unfamiliar region's still format and animation formats.

Posttest questionnaire results showed that though subjects spent more time on the animated format questions, they perceived that they spent less time. Subjects preferred the slider format on all types of questions almost two to one over the play format because the slider format allowed the subject both to view the transformation and control its speed and direction.

Overall, the results of the experiment indicated that animation of the transformation between the geographic map and the cartogram does have an effect on the cartogram's ability to communicate. Though it may take more time to receive the message as the animated transformation is viewed repeatedly, subjects perceive that they actually spend *less* time on the animated cartograms. They also overwhelmingly preferred the animated formats.

Though this experiment could undergo some revision, such as using a different method of constructing cartograms, recruiting a larger number of test subjects from a wider population, and asking a greater number of questions, the results provide valuable information about the use of animation in cartography. In the words of one subject, the animations "[were] great for exposure to cartograms, even if [the purpose] was nothing more than that." The higher level of accuracy with the animated versions, the comparable level of accuracy with both familiar and unfamiliar regions when animation was used, and the interest that the animations elicit combine to present a strong case for using animation with cartograms.

APPENDICES

APPENDIX A

Avenue code for creating cartograms in ArcView

```
av.ClearStatus
theProject = av.GetProject
theView = av.GetActivedoc
thePrj = theView.GetProjection
if (thePrj = nil) then
  hasPrj = false
else
  hasPrj = true
end

theAttributeValue = nil
theCurrentThemes = theView.GetThemes
theGoTheme = Msgbox.Choice(theCurrentThemes, "Select a
theme: ", "Convert Theme to Cartogram")
if (theGoTheme = nil) then
  exit
end

theTheme = theGoTheme
anFtab = theTheme.GetFtab
theFieldList = anFtab.GetFields

while (theAttributeValue = nil)
  theAttributeValue = Msgbox.Choice(theFieldList,"Select an
attribute: ", "Selected Theme is"++theTheme.AsString).
AsString
  theContents = anFtab.ReturnValue(anFtab.FindField
(theAttributeValue), 0)
  if (theAttributeValue = "Area" or theContents.AsString.
IsNumber.Not) then
    Msgbox.Info("Selecting"++theAttributeValue++"as an
attribute will not produce a cartogram.", "Select Another
Attribute!")
    theAttributeValue = nil
  end
end

iteration = nil
while (iteration = nil)
  iteration = Msgbox.Input("Enter number of iterations to
generate cartogram: ", "Iterations", "8").AsNumber
  if (iteration < 1) then
```

```
    MsgBox.Info("Cannot perform negative iterations.  Try
again.", "Oops!")
    iteration = nil
  end
end

def = (theTheme.GetName.Left(3) + iteration.AsString +
"_cg.shp").AsFileName
tbl = anFtab

shpfld = (tbl.FindField("Shape"))
if (shpfld.IsVisible.Not) then
  shpfld.SetVisible(shpfld.IsVisible.Not)
  wasNotVisible = TRUE
else
  wasNotVisible = FALSE
end

anFtab = tbl.Export(def, Shape, FALSE)
anFtab.SetEditable(TRUE)

if (wasNotVisible) then
  shpfld.SetVisible(FALSE)
end

iterationCount = 1
PI = Number.GetPI
PolygonValueList = {}
TotalValue = 0
TotalPoints = 0
PolygonAreaList = {}
TotalArea = 0

for each xnum in anFtab
  theShape = anFtab.ReturnValue(anFtab.FindField("Shape"),
xnum)
  PointsInEachPolygon = theShape.AsList.Get(0).Count
  TotalPoints = TotalPoints + PointsInEachPolygon
  PolygonValueList.Add(anFtab.ReturnValue(anFtab.
FindField(theAttributeValue), xnum))
  TotalValue = TotalValue + PolygonValueList.Get(xnum)
  PolygonAreaList.Add(anFtab.ReturnValue(anFtab.
FindField("Area"), xnum))
  TotalArea = TotalArea + PolygonAreaList.Get(xnum)
end

OutputFile = LineFile.Make("debug.dat".AsFileName,
#FILE_PERM_WRITE)

while (iterationCount <= iteration)
```

```
av.ShowMsg("Distorting original polygons: iteration #" +
iterationCount.AsString)
PolygonAreaList = {}
CentroidList = {}
DesiredList = {}
RadiusList = {}
MassList = {}
SizeErrorList = {}
SizeErrorTotal = 0
count = 0

OutputFile.WriteElt("Iteration
#"++iterationCount.AsString++"of"++iteration.AsString)

for each xnum in anFtab
  theShape = anFtab.ReturnValue(anFtab.FindField("Shape"),
xnum)
PolygonAreaList.Add(anFtab.ReturnValue(anFtab.FindField
("Area"), xnum))
  CentroidList.Add(theShape.ReturnCenter)
end

OutputFile.WriteElt("Poly#  Value Value% PolyArea Poly%
DesiredArea Desired% SizeError")

for each xnum in anFtab
  PolygonValue = PolygonValueList.Get(xnum)
  PolygonArea = PolygonAreaList.Get(xnum)
  Desired = TotalArea * (PolygonValue/TotalValue)
  DesiredList.Add(Desired)
  Radius = (PolygonArea/PI).Sqrt
  RadiusList.Add(Radius)
  Mass = ((Desired/PI).Sqrt) - ((PolygonArea/PI).Sqrt)
  MassList.Add(Mass)
  SizeError = (PolygonArea Max Desired)/(PolygonArea Min
Desired)
  SizeErrorTotal = SizeError + SizeErrorTotal
  SizeErrorList.Add(SizeError)

OutputFile.WriteElt(xnum.AsString++PolygonValue.AsString++Po
lygonValue/TotalValue*100).AsString++PolygonArea.
AsString++(PolygonArea/TotalArea*100).AsString++Desired.
AsString++((PolygonAreaDesired).Abs/Desired*100).AsString++S
izeError.AsString)
end

MeanError = SizeErrorTotal/SizeErrorList.Count
ForceReductionFactor = 1/(1 + MeanError)

for each r in anFtab
```

```
  theShape = anFtab.ReturnValue(anFtab.FindField("Shape"),
r)
  theListofPoints = theShape.AsList.Get(0)
  theNewPointList = List.Make

  for each OriginalPoint in theListofPoints
    x = OriginalPoint.GetX
    y = OriginalPoint.GetY
    tempX = x
    tempY = y

    for each centroid in anFtab
      theCentroid = CentroidList.Get(centroid)
      cx = theCentroid.GetX
      cy = theCentroid.GetY
      distX = x - cx
      distY = y - cy
      Distance = OriginalPoint.Distance(theCentroid)
      Desired = DesiredList.Get(centroid)
      Radius = RadiusList.Get(centroid)
      Mass = MassList.Get(centroid)

      if (Distance > Radius) then
        Fij = Mass * (Radius/Distance)
      else
        Fij = Mass * ((Distance^2)/(Radius^2))*(4-3*
(Distance/Radius))
      end

      Fij = Fij * ForceReductionFactor/Distance
      tempX = tempX + (Fij * distX)
      tempY = tempY + (Fij * distY)
    end

    theNewPointList.Add(tempX@tempY)
    count = count + 1
    av.SetStatus(100*(count/TotalPoints))
  end

  theNewShape = Polygon.Make({theNewPointList})
  anFtab.SetValue(anFtab.FindField("Shape"), r, theNewShape)
  theNewShape = anFtab.ReturnValue(anFtab.FindField
("Shape"), r)
  theAreaField = anFtab.FindField("Area")
  thePerimeterField = anFtab.FindField("Perimeter")
  anFtab.QueryShape(r,thePrj,theNewShape)
  theArea = theNewShape.ReturnArea
  thePerimeter = theNewShape.ReturnLength
  anFtab.SetValue(theAreaField, r, theArea)
  anFtab.SetValue(thePerimeterField, r, thePerimeter)
```

```
end

def = (theTheme.GetName.Left(3) + iterationCount.AsString +
"acg.shp").AsFileName
iterationCount = iterationCount + 1
anFtab.Export(def,Shape,FALSE)
end

MsgBox.Info("The mean error is"++MeanError.AsString++".",
"Mean Error")

anFtab.SetEditable(FALSE)
av.ClearMsg
av.ClearStatus

fthm = FTheme.Make(anFtab)
theView.AddTheme(fthm)
theView.GetWin.Activate
```

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APPENDIX B

Text of the cartogram test

This appendix contains the text of the cartogram test in its entirety. The names of the labeled enumeration units for each task are displayed in brackets. The correct responses to the third task are also displayed in brackets. Obviously, this information was not included on the actual test screen but is included here to inform the reader. The order of the cartograms is only one of the three orders that were used. All text remained the same for each cartogram, no matter what order the cartogram appeared in.

To obtain a copy of the cartogram test program in its original softcopy form, please contact the author at warejen1@pilot.msu.edu. This email address is valid until December 2000.

Frame 1. Cartogram Test. Click NEXT to continue.

Frame 2. A cartogram is a map on which enumeration units such as states or provinces are drawn proportionate to some variable other than geographic space. The size of an enumeration unit represents the data value of that enumeration unit. For example, states may be drawn proportionate to their population.

Frame 3. This is a geographic map of the New England region of the United States, where the states are drawn proportionate to geographic space.

Frame 4. This is a cartogram of New England, where the states are drawn proportionate to the number of births. Click BACK to compare with the geographic map.

Frame 5. Now that you've been introduced to the concept of a cartogram, answer the following question by clicking on one of the circles to the left.
A cartogram is a map on which...

- The sizes of the enumeration units are randomly changed. Larger units have no real significance.
- The sizes of the enumeration units are the same as on a geographic map. Larger units indicate larger land area.

- The sizes of the enumeration units represent the data. Larger units indicate larger data values.
- The sizes of the enumeration units mean nothing. Larger units are no different than smaller units.

Frame 6a. Oops! Try again. Go back and read the definition.

Frame 6b. Correct! You understand the definition. Please continue.

Frame 7. Cartograms can be animated, allowing you to view the transformation between the geographic map and the cartogram. The following screens will display examples of two different types of animation. Use the "Auto Play/Slide Play button to explore both formats as many times as you wish. Click NEXT from either screen when you are familiar with both formats.

Frame 8. Click PLAY to automatically transform the map into the cartogram. Click REWIND to reverse the transformation.

Frame 9. Click on the red diamond and drag it anywhere within the white column to manually control the transformation between the map and the cartogram.

Frame 10. The test will ask three questions about each of twelve cartograms. You will be able to refer to the cartograms while answering the questions. Be sure to study the cartograms carefully. You will get only one chance to answer each question. Once you select your answer, you will move automatically to the next screen. The following screens show examples of the types of questions you will be asked. Answer the questions as if you were taking the test.

Frame 11. This is a sample test screen. Answer the sample question.
Objective: Find the state on the cartogram that corresponds to state A on the geographic map.
[Answer: Vermont]
Instructions: Click once on the corresponding state on the cartogram.

Frame 12. This is another sample test screen. Answer the sample question.
Objective: Find the state on the cartogram that corresponds to state B on the geographic map.
[Answer: Massachusetts]
Instructions: Click once on the corresponding state on the cartogram.

Frame 13. This is a third sample test screen. Answer the sample question.

Objective: Using the cartogram, determine which state, A or B, has the **greater number of births**.
[Answer: B]
Instructions: Click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 14. This ends the introduction. Do you want to view the introduction again? Are you ready to begin the test?

Frame 15. Cartogram 1 [United States/Population/Still]

Frame 16. Objective: Find the state on the cartogram that corresponds to state A on the geographic map.
[Answer: Utah]
Instructions: Click once on the corresponding state on the cartogram.

Frame 17. Objective: Find the state on the cartogram that corresponds to state B on the geographic map.
[Answer: Arkansas]
Instructions: Click once on the corresponding state on the cartogram.

Frame 18. Objective: Using the cartogram, determine which state, A or B, has the **greater population.**
[Answer: Equal or adjusted answer B]
Instructions: Click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 19. Cartogram 2 [United States/Cattle/Still]

Frame 20. Objective: Find the state on the cartogram that corresponds to state A on the geographic map.
[Answer: Indiana]
Instructions: Click once on the corresponding state on the cartogram.

Frame 21. Objective: Find the state on the cartogram that corresponds to state B on the geographic map.
[Answer: Wyoming]
Instructions: Click once on the corresponding state on the cartogram.

Frame 22. Objective: Using the cartogram, determine which state, A or B, has the **greater number of cattle**.
[Answer: B]
Instructions: Click on one of the following answers.

- A is greater
- B is greater

- A and B are equal

Frame 23. Cartogram 3 [United States/Population/Play]

Frame 24. Objective: Find the state on the cartogram that corresponds to state A on the geographic map.
[Answer: Kansas]
Instructions: Click PLAY to transform the lower map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click once on the corresponding state on the cartogram.

Frame 25. Objective: Find the state on the cartogram that corresponds to state B on the geographic map.
[Answer: Pennsylvania]
Instructions: Click PLAY to transform the lower map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click once on the corresponding state on the cartogram.

Frame 26. Objective: Using the cartogram, determine which state, A or B, has the **greater population**.
[Answer: B]
Instructions: Click PLAY to transform the lower map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 27. Cartogram 4 [United States/Cattle/Play]

Frame 28. Objective: Find the state on the cartogram that corresponds to state A on the geographic map.
[Answer: Kentucky]
Instructions: Click PLAY to transform the lower map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click once on the corresponding state on the cartogram.

Frame 29. Objective: Find the state on the cartogram that corresponds to state B on the geographic map.
[Answer: Nevada]
Instructions: Click PLAY to transform the lower map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click once on the corresponding state on the cartogram.

Frame 30. Objective: Using the cartogram, determine which state, A or B, has the **greater number of cattle**.
[Answer: A]
Instructions: Click PLAY to transform the lower map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click on one of the following answers.

- A is greater

- B is greater
- A and B are equal

Frame 31. Cartogram 5 [United States/Population/Slider]

Frame 32. Objective: Find the state on the cartogram that corresponds to state A on the geographic map.
[Answer: Missouri]
Instructions: Click on the red diamond and drag within the white column to transform the lower map into a cartogram. Then, click once on the corresponding state on the cartogram.

Frame 33. Objective: Find the state on the cartogram that corresponds to state B on the geographic map.
[Answer: Connecticut]
Instructions: Click on the red diamond and drag within the white column to transform the lower map into a cartogram. Then, click once on the corresponding state on the cartogram.

Frame 34. Objective: Using the cartogram, determine which state, A or B, has the **greater population**.
[Answer: A]
Instructions: Click on the red diamond and drag within the white column to transform the lower map into a cartogram. Then, click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 35. Cartogram 6 [United States/Cattle/Slider]

Frame 37. Objective: Find the state on the cartogram that corresponds to state A on the geographic map.
[Answer: Colorado]
Instructions: Click on the red diamond and drag within the white column to transform the lower map into a cartogram. Then, click once on the corresponding state on the cartogram.

Frame 38. Objective: Find the state on the cartogram that corresponds to state B on the geographic map.
[Answer: Tennessee]
Instructions: Click on the red diamond and drag within the white column to transform the lower map into a cartogram. Then, click once on the corresponding state on the cartogram.

Frame 39. Objective: Using the cartogram, determine which state, A or B, has the **greater number of cattle**.
[Answer: Equal or adjusted answers A and B]
Instructions: Click on the red diamond and drag within the white column to transform the lower map into a cartogram. Then, click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 40. Cartogram 7 [China/Population/Still]

Frame 41. Objective: Find the province on the cartogram that corresponds to province A on the geographic map. [Answer: Sichuan]
Instructions: Click once on the corresponding province on the cartogram.

Frame 42. Objective: Find the province on the cartogram that corresponds to province B on the geographic map. [Answer: Shanxi]
Instructions: Click once on the corresponding province on the cartogram.

Frame 43. Objective: Using the cartogram, determine which province, A or B, has the **greater population**. [Answer: A]
Instructions: Click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 44. Cartogram 8 [China/Cattle/Still]

Frame 45. Objective: Find the province on the cartogram that corresponds to province A on the geographic map. [Answer: Fujian]
Instructions: Click once on the corresponding province on the cartogram.

Frame 46. Objective: Find the province on the cartogram that corresponds to province B on the geographic map. [Answer: Henan]
Instructions: Click once on the corresponding province on the cartogram.

Frame 47. Objective: Using the cartogram, determine which province, A or B, has the **greater number of cattle**. [Answer: B]
Instructions: Click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 48. Cartogram 9 [China/Population/Play]

Frame 49. Objective: Find the province on the cartogram that corresponds to province A on the geographic map. [Answer: Qinghai]
Instructions: Click PLAY to transform the right-hand map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired.

Then, click once on the corresponding province on the cartogram.

Frame 50. Objective: Find the province on the cartogram that corresponds to province B on the geographic map. [Answer: Hunan]
Instructions: Click PLAY to transform the right-hand map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click once on the corresponding province on the cartogram.

Frame 51. Objective: Using the cartogram, determine which province, A or B, has the **greater population**. [Answer: B]
Instructions: Click PLAY to transform the right-hand map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 52. Cartogram 10 [China/Cattle/Play]

Frame 53. Objective: Find the province on the cartogram that corresponds to province A on the geographic map. [Answer: Gansu]
Instructions: Click PLAY to transform the right-hand map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click once on the corresponding province on the cartogram.

Frame 54. Objective: Find the province on the cartogram that corresponds to province B on the geographic map. [Answer: Hubei]
Instructions: Click PLAY to transform the right-hand map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click once on the corresponding province on the cartogram.

Frame 55. Objective: Using the cartogram, determine which province, A or B, has the **greater number of cattle**. [Answer: A or adjusted answer Equal]
Instructions: Click PLAY to transform the right-hand map into a cartogram. Click REWIND to reverse the transformation. Repeat as desired. Then, click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 56. Cartogram 11 [China/Population/Slider]

Frame 57. Objective: Find the province on the cartogram that corresponds to province A on the geographic map. [Answer: Yunnan]
Instructions: Click on the red diamond and drag within the white column to transform the right-hand map into a cartogram. Then, click once on the corresponding province on the cartogram.

Frame 58. Objective: Find the province on the cartogram that corresponds to province B on the geographic map. [Answer: Jiangxi]
Instructions: Click on the red diamond and drag within the white column to transform the right-hand map into a cartogram. Then, click once on the corresponding province on the cartogram.

Frame 60. Objective: Using the cartogram, determine which province, A or B, has the **greater population**. [Answer: Equal or adjusted answer A]
Instructions: Click on the red diamond and drag within the white column to transform the right-hand map into a cartogram. Then, click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 61. Cartogram 12 [China/Cattle/Slider]

Frame 62. Objective: Find the province on the cartogram that corresponds to province A on the geographic map. [Answer: Shaanxi]
Instructions: Click on the red diamond and drag within the white column to transform the right-hand map into a cartogram. Then, click once on the corresponding province on the cartogram.

Frame 63. Objective: Find the province on the cartogram that corresponds to province B on the geographic map. [Answer: Anhui]
Instructions: Click on the red diamond and drag within the white column to transform the right-hand map into a cartogram. Then, click once on the corresponding province on the cartogram.

Frame 64. Objective: Using the cartogram, determine which province, A or B, has the **greater number of cattle**. [Answer: B]
Instructions: Click on the red diamond and drag within the white column to transform the right-hand map into a cartogram. Then, click on one of the following answers.

- A is greater
- B is greater
- A and B are equal

Frame 65. The test is now over. Thank you again for your participation.

APPENDIX C

Pretest and posttest questionnaires

PRE-TEST QUESTIONNAIRE

Number ________ Gender ( )M ( )F Age _______

General Experience with Cartograms

1. Have you ever heard of a map called a cartogram before?
   ( )yes ( )no

2. If yes, what is your definition of a cartogram?

3. Have you seen a cartogram in any of these contexts? Check all that apply.
   ( )have never seen a cartogram
   ( )in an atlas
   ( )in a textbook
   ( )in a classroom, used by a teacher as a visual aid
   ( )in a journal, newspaper or other printed media
   ( )on the Internet, television or other electronic media
   ( )other - please describe:

4. Have you used a cartogram in any of these contexts? Check all that apply.
   ( )have never used a cartogram
   ( )in a classroom exercise or lesson
   ( )to answer a test question
   ( )for personal reference
   ( )included someone else's cartogram in your paper or project
   ( )created your own cartogram for use in a paper or project
   ( )other - please describe:

Checking Your Mental Maps of the United States and China

The following questions require the most time and effort. You may take up to 15 minutes to complete these two questions. Try to be as accurate as you can, but don't be embarrassed by your effort. You are not receiving a score on this part of the test, and you will not be asked to answer any other questions like these.

5. Using only your memory, draw a map of the continental United States with as many individual states as you can. Please label as many states as possible.

6. Using only your memory, draw a map of the People's Republic of China with as many individual provinces as you can. Please label as many provinces as possible.

POST-TEST QUESTIONNAIRE

Number ________

Assessment of the Testing Experience

1. Had you ever taken a computerized test like this one before?
   ( )yes ( )no

2. Did you feel comfortable using the computer to take the test?
   ( )yes ( )neutral ( )no

3. Did you feel the introduction adequately prepared you to take the test?
   ( )yes ( )neutral ( )no

4. If you said no, in what way did you feel unprepared?

5. Was the definition of a cartogram helpful?
   ( )yes ( )neutral ( )no

6. Were the examples of the different formats (automatic animation, manual animation) helpful?
   ( )yes ( )neutral ( )no

7. Were the examples of the test questions helpful?
   ( )yes ( )neutral ( )no

8. Was it easy to navigate through the testing program?
   ( )yes ( )neutral ( )no

9. If you said no, what part of the program was difficult to navigate?

10. Which format did you find easiest and fastest to use to locate areas A and B?
   ( )static, no movement
   ( )automatically animated using the "play" button
   ( )manually animated using the slider bar

11. Why did you prefer your choice?

12. Which format did you find easiest and fastest to use to compare the sizes of A and B?
   ( )static, no movement
   ( )automatically animated using the "play" button
   ( )manually animated using the slider bar

13. Why did you prefer your choice?

14. Do you think that cartograms could be a useful tool for presenting spatial information?
   ( )yes ( )neutral ( )no

15. Why or why not?

16. Any other comments about cartograms or the testing experience?

APPENDIX D

Samples of mental maps

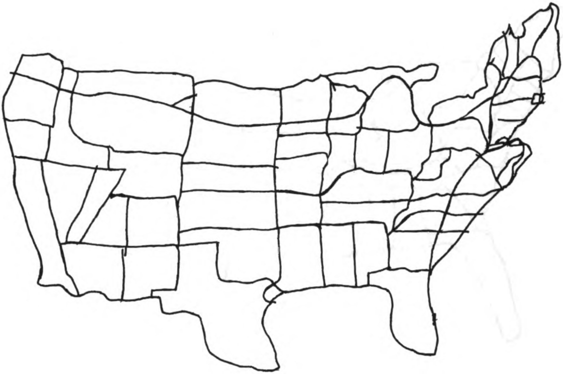

Figure 18. Sketch map of the United States (1). Forty-eight states were identified. States are generally in the correct positions and care was taken to draw correct shapes and maintain topology. All states were labeled correctly, but labels were deemed indistinct for printing purposes and removed from this copy.

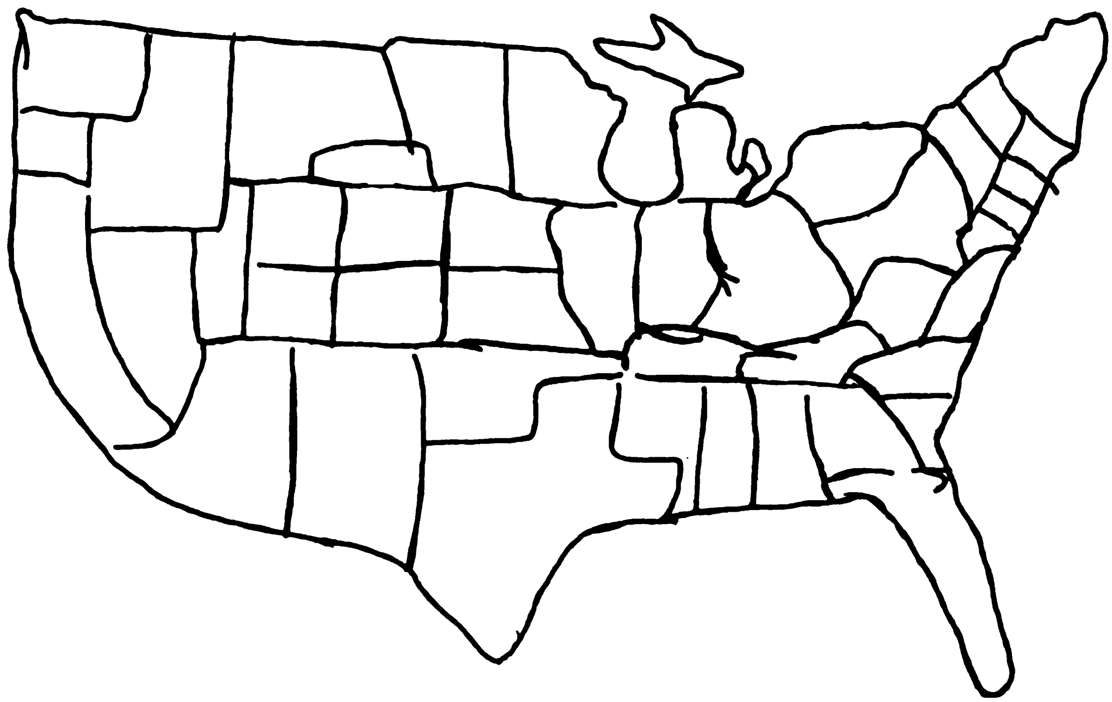

Figure 19. Sketch map of the United States (2). Forty-four states were identified. States are generally in the correct positions, but less effort was taken with regard to correct shape. Most states were labeled correctly, but labels were deemed indistinct for printing purposes and removed from this copy.

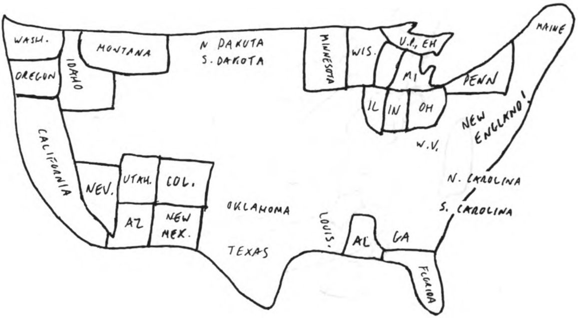

Figure 20. Sketch map of the United States (3).
Twenty-nine states were identified. States are generally in the correct positions, and some are the correct shape. Others are noted only by name.

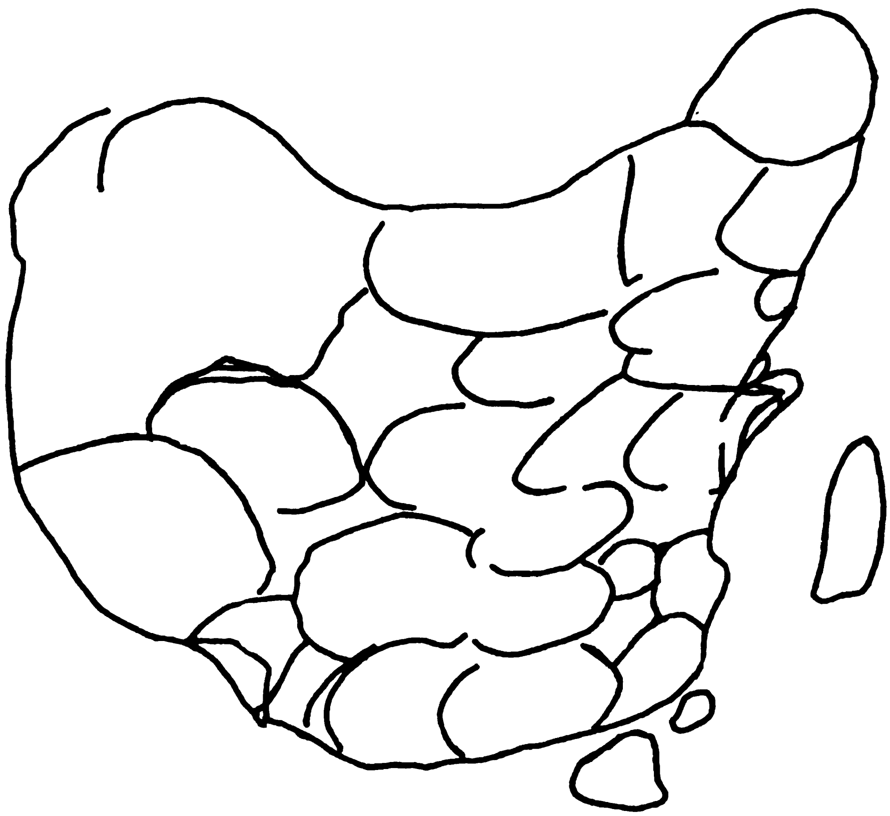

Figure 21. Sketch map of China (1).
Twenty-seven provinces were identified. Provinces are generally in the correct positions, but little effort has been taken to maintain correct shape. Most provinces were labeled correctly, but labels were deemed indistinct for printing purposes and removed from this copy.

Figure 22. Sketch map of China (2).
Two provinces have been identified, one in the wrong location. The general shape of the country is correct though the province shapes are not.

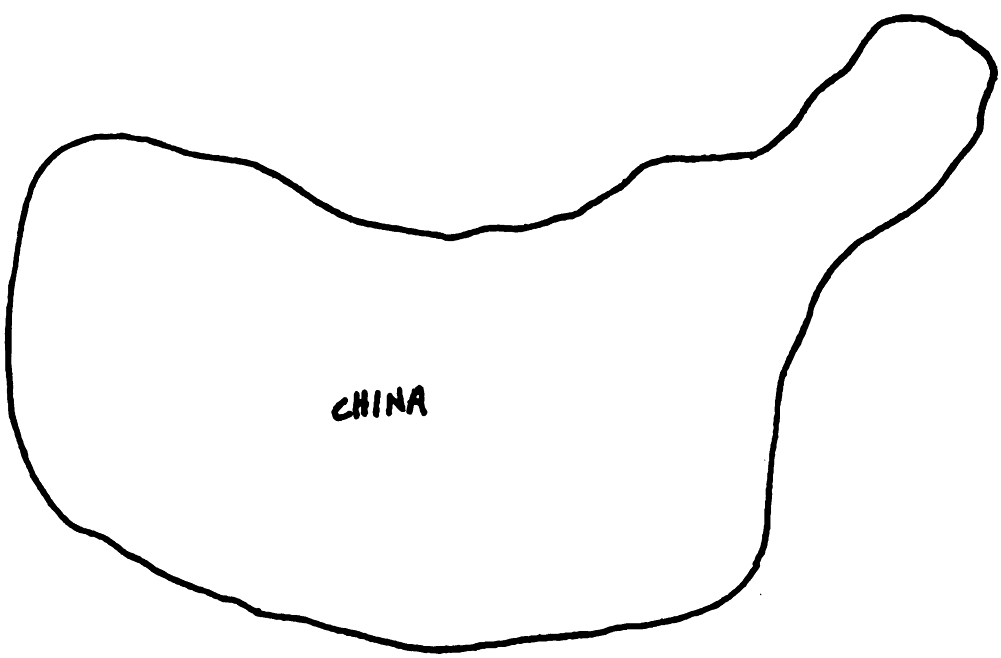

Figure 23. Sketch map of China (3).
No provinces have been identified. An attempt was made to draw the correct outline of the country.

BIBLIOGRAPHY

BIBLIOGRAPHY

Attneave, Fred. 1954. "Some informational aspects of visual perception." *Psychological Review* 61:3, 183-193.

Blades, M. 1990. "The reliability of data collected from sketch maps." *Journal of Environmental Psychology* 10, 327-339.

Boyce, Ronald, William Clark. 1964. "The concept of shape in geography." *Geographical Review* 54, 561-572.

Campbell, Craig S., Stephen L. Egbert. 1990. "Animated cartography: thirty years of scratching the surface." *Cartographica* 27:2, 24-46.

Colby, W. Hunter, Frederick W. Crook, Shwu-Eng H. Webb. "Table 139, Cattle slaughter, by region and province, China, 1979-1993." *Agricultural Statistics Database of the People's Republic of China, 1949-1993.* April 1998. http://usda.mannlib.cornell.edu/data-sets/international/90014/cattlesl.wk1 (June 9, 1998).

Dent, Borden D. 1972. "A note on the importance of shape in cartogram communication." *Journal of Geography* 71:7, 393-401.

Dent, Borden D. 1975. "Communication aspects of value-by-area cartograms." *The American Cartographer* 2:2, 154-168.

Dent, Borden D. 1993. *Cartography: Thematic Map Design.* Dubuque: William C. Brown Communications, Inc. 209-224.

DiBiase, David, Alan M. MacEachren, John B. Krygier, Catherine Reeves. 1992. "Animation and the role of map design in scientific visualization." *Cartography and Geographic Information Systems* 19:4, 201-214.

Dorling, Daniel. 1994. "Bringing elections back to life." *Geographical Magazine* 66:12, 20-21.

Dougenik, James A., Nicholas R. Chrisman, Duane R. Niemeyer. 1985. "An algorithm to construct continuous area cartograms." *The Professional Geographer* 37:1, 75-81.

Gersmehl, Philip J. 1990. "Choosing tools: nine metaphors for four dimensional cartography." *Cartographic Perspectives* 5, 3-17.

Getis, Arthur. 1963. "The determination of the location of retail activities with the use of a map transformation." *Economic Geography* 39, 14-22.

Griffin, T.L.C. 1983. "Recognition of areal units on topological cartograms." *The American Cartographer* 10:1, 17-29.

Gusein-Zade, Sabir M., Vladimir S. Tikunov. 1993. "A new technique for constructing continuous cartograms."" *Cartography and Geographic Information Systems* 20:3, 167-173.

Harris, Chauncy D., George B. McDowell. 1955. "Distorted maps: a teaching device." *Journal of Geography* 54, 286-289.

Hunter, John M. and Jonathan C. Young. 1968. "A technique for the construction of quantitative cartograms by physical accretion models." *The Professional Geographer* 20:6, 402-407.

Jackel, Charles B. 1997a. "Using ArcView to create contiguous and noncontiguous area cartograms." *Cartography and Geographic Information Systems* 24:2, 101-109.

Jackel, Charles B. "Animated cartogram." *Creating cartograms with ArcView GIS*. 1997b. http://idt.net /~jackel (May 1, 1998)

Kadmon, Naftali. 1982. "Cartograms and topology." *Cartographica* 19:3-4, 1-17.

Karl, Doris. 1992. "Cartographic animation: potential and research issues." *Cartographic Perspectives* 13, 3-9.

Kennedy, John M., Ramona Domander. 1985. "Shape and contour: the points of maximum change are least useful for recognition." *Perception* 14, 367-370.

Liu, Chuang, Yao Xurong, William Lavely et al. "China Administrative Regions GIS Data: 1:1M, County Level, 1990, Published and Disseminated by CIESIN." *China in Time and Space*. May 1996. ftp://ftpserver.ciesin.org/pub/data /China/adm_bnd90/CTSAR90.bnd90 (June 3, 1998).

Milheim, William D. 1993. "How to use animation in computer assisted learning." *British Journal of Educational Technology* 24:3, 171-178.

Moellering, Harold. 1973. "The automated mapping of traffic crashes." *Surveying and Mapping* 33:4, 467-477.

Monmonier, Mark S. 1985. *Technological Transition in Cartography.* Madison: University of Wisconsin Press.

National Agricultural Statistics Service. "Table 14, Cattle and Calves - Inventory and Sales: 1992, 1987 and 1982." *1992 Census of Agriculture, Volume 1: Part 51, Chapter 2; United States Summary and State Data; State-level Data.* 1992. http://www.nass.usda.gov/census /census92/volume1/us-51/toc292.htm (June 9, 1998).

National Oceanic and Atmospheric Administration. "CONUS States." *NWS Shapefile Catalog.* Oct 21, 1996. http://www.nws.noaa.gov/pub/modernize/shapemap/states/ us_state.shp (June 3, 1998).

Olson, Judy M. 1976. "Noncontiguous area cartograms." *The Professional Geographer* 28:4, 371-380.

Olson, Judy M. 1997. "Multimedia in geography: good, bad, ugly or cool?" *Annals of the Association of American Geographers* 87:4, 571-578.

Park, Ok-Choon, Reginald Hopkins. 1993. "Instructional conditions for using dynamic visual displays: a review." *Instructional Science* 21, 427-449.

Peterson, Michael P. 1993. "Interactive cartographic animation." *Cartography and Geographic Information Systems* 20:1, 40-44.

Quinlan, Philip T. 1991. "Differing approaches to two-dimensional shape recognition." *Psychological Bulletin* 109:2, 224-241.

Raisz, Erwin. 1934. "The rectangular statistical cartogram." *Geographical Review* 24, 292-296.

Rittschof, Kent A., William A. Stock, Raymond W. Kulhavy, Michael P. Verdi, Janet T. Johnson. 1996. "Learning from cartograms: the effects of region familiarity." *Journal of Geography* 95:2, 50-58.

Skinner, G. William et al. "China County-Level Data on Population (Census) and Agriculture, Keyed to 1:1M GIS Map, Published and Disseminated by CIESIN." *China in Time and Space*. February 1997. ftp://ftp.ciesin.org/pub/data /China/CITAS/census_agr/chinadbf.zip (June 3, 1998).

Thrower, Norman. 1959. "Animated cartography." *The Professional Geographer* 11:6, 9-12.

Tobler, Waldo R. 1963. "Geographic area and map projections." *Geographical Review* 53, 59-78.

Tobler, Waldo R. 1970. "A computer movie simulating urban growth in the Detroit region." *Economic Geography* 46, 234-240.

Tobler, Waldo R. 1973. "A continuous transformation useful for districting." *New York Academy of Sciences Annals* 219, 215-220.

Tobler, Waldo R. 1986. "Pseudo-cartograms." *The American Cartographer* 13:1, 43-50.

United States Census Bureau. "Summary Tape File 3 on CD-ROM [machine-readable data files]/prepared by the Bureau of the Census." *Census of Population and Housing, 1990*. 1992. http://www.census.gov (June 3, 1998).

Ware, Jennifer A. 1997. "The effectiveness of animating geologic processes in a classroom setting." Unpublished seminar paper.

Weber, Christopher R., Barbara P. Buttenfield. 1993. "A cartographic animation of average yearly surface temperatures for the 48 contiguous United States: 1897-1986." *Cartography and GIS* 20:3, 141-50.

Wilkinson, Leland, Grant Blank, Christian Gruber. 1996. *Desktop Analysis with Systat*. Upper Saddle River: Prentice Hall. 475-487.

Woytinsky, Wladimir S., Emma Shadkhan Woytinsky. 1953. *World Population and Production: Trends and Outlook*. New York: Twentieth Century Fund. 42-45.