A Cognitive Map Experiment: Mental Representations and the Encoding Process

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Abstract:
Researchers have long debated the mental representation of knowledge. The theories initially spawned by this debate were propositional theory, imagery theory, and dual-coding theory. Related research further suggests that knowledge encoding processes such as landmark-based and path-based learning may also affect these representations. Such theories form a basis from which cartographers can begin to explore the mental representations of spatial knowledge. The purpose of this study was to assess the mental organization of spatial information and to examine the effect of varying the encoding process. An experiment was conducted in which subjects studied a map presented to them using one of three encoding processes and one of two grid conditions. Subjects then examined a series of test maps and determined whether each map was the same as or different from the original studied map. Test maps that differed from the original map studied were modified by either replacing, displacing, or reversing the perspective of a map object, Results of the study indicated that the type of encoding process, type of map modification, and type of spatial object manipulated all significantly affected the accuracy with which subjects completed the tasks.
KEYWORDS: cognitive map, imagery coding, propositional coding, landmark-based learning, path-based learning, spatial encoding processes.

Article:

Introduction

A map is much more than a graphic composition of abstract symbols. Like a written language, it facilitates knowledge itself, as well as communication between people. As a form of knowledge representation, a map can be thought of both as a tangible object and as an embodiment of mental concepts. These mental concepts are closely associated with the notion of a cognitive map, which essentially can be defined as a mental image with spatial attributes (Dent 1996), Cognitive mapping has been defined by Downs and Stea (1973, 9) as:

> a process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in his everyday spatial environment.

Cognitive maps and cognitive mapping have fascinated researchers from many disciplines, including geography. Cartographers, in particular, have a stake in exploring the process of cognitive mapping. To design effective maps, cartographers must strive to understand not only the perceptual limitations of the map reader, but also the mental processes used to interpret and analyze the information presented on the map. Knowledge of spatial decision-making processes is essential to understanding how maps and human spatial behavior are intertwined (Gilmartin 1981; Lloyd 1982).

Psychologists have long debated the internal representation that information takes once it is encoded within the mind. Three theories that initially grew out of this debate are:

- propositional theory (Pylyshyn 1973; Anderson and Bower 1973),

- imagery theory (Kosslyn and Pomerantz 1977), and
- dual-coding theory (Paivio 1977).

The primary difference between these theories is the degree to which each has imagery as an integral part of the internal representation of information. All three theories are supported by empirical evidence, which leaves researchers to continue to grapple with this issue. One recent study, conducted by Talasli (1990), suggests that the techniques used to assess cognitive representations are to blame for the different conclusions.

Related to the issue of internal representation is the question of whether these representations may be modified by varying the encoding process. Current theory suggests that encoding processes can affect the underlying mental representation of information (Evans and Pezdek 1980; Thorndyke and Hayes-Roth 1982; Shimron 1978; MacEachren 1992). Research indicates that humans form cognitive maps by encoding fragments of knowledge that are eventually linked together during the construction of the cognitive representation (MacEachren 1992; Coudelis et al. 1987). Two theories that describe this building process are path-based learning (Appleyard 1970) and landmark-based learning (Siegal and White 1975; Gofledge 1978). Both offer slightly different versions of how the resulting cognitive map is formed. The purpose of this research was two-fold:

1. to assess the internal representations of cognitive maps using a methodology introduced by Talasli (1990), and

2. to examine the effect that varying the encoding process had on that resulting structure.

Cognitive Representations and Maps

The Three Major Theories

Propositional Theory

A proposition, by definition, is an abstract conceptual structure that expresses the relationships between objects. A proposition must meet three basic criteria:

1, it must be abstract,

2. it must be associated with a truth value, and

3. it must adhere to certain rules of formation (Anderson 1978).

Propositions are often approximated by using simple sentences (i.e., "Oklahoma is north of Texas"), but they are not necessarily linguistic structures; ideas that lack verbal labels can also be represented in this way. The key to this theory is the realization that these structures do not encode the actual physical characteristics of information but only the abstract meaning. Propositional theory, then, "argues against considering imagery as a qualitatively distinct or theoretically adequate form of mental representation" (Kosslyn and Pomerantz 1977).A number of researchers support this position (Anderson and Bower 1973; RumeMart et al. 1972), but Pylyshyn (1973; 1981) is the major proponent.

Imagery Theory

Unlike propositional theorists, proponents of imagery theory (Kosslyn 1981; Kosslyn and Pomerantz 1977; Shepard 1978; Finke 1979) believe that the image is an essential component of the spatial cognition model. The basis of this theory is a picture metaphor, but imagery theory does not assume that images are equivalent to pictures. Rather, it proposes that the perception process takes raw spatial information and reduces it into a simpler, more organized format. Once reorganized, the information is stored in memory and can be reassembled as-needed to create quasi-pictorial images. Mental images, then, are not equivalent to perceptions, but the theory does assert that the two share a common format that is different from the formats of non-visual representations (Kosslyn and Pomerantz 1977). Cartographers are attracted to imagery theory because it implies that one's cognitive map could be functionally equivalent to the cartographic map (Lloyd 1982).

Dual-Coding Theory

Dual-coding theory was proposed by Paivio (1977; 1991). This theory holds that verbal and visual information is processed independently, but that the systems processing these types of information are interconnected. Under dual-coding theory, an imagery system organizes simplified images into a hierarchical structure and outputs this information in a spatial format. A parallel verbal system processes all non-visual information and organizes it into a higher-ordered sequential structure. The connection between the systems is not assumed to be representative of a one-to-one correspondence, but more like a partial interconnectedness (Paivio 1977). For example, a map would cause primary activation of the imagery system and secondary activation of the verbal system. Verbal directions, on the other hand, would have just the opposite effect. Anderson (1978) has proposed a similar model, and Kosslyn's (1981, 51) more recent research also supports this position; he reports findings that "suggest that there are two types of representations in long-term memory that can be used to generate images, which we call literal and propositional."

Research Results Using Spatial Information

Only a few studies have used a map as the base from which to explore the representational format of spatial knowledge. Evans and Pezdek (1980) conducted one of the earliest psychological studies that specifically targeted map knowledge. Using two types of spatial knowledge, navigational and map-related, they asked subjects to determine the relative positional accuracy of triads of locations. The authors used triads of campus buildings to represent navigational knowledge and triads of U,S. states to represent map knowledge. Results showed that subjects displayed an orientation bias for the state triads. In other words, their response times increased linearly with the number of degrees away from north that the triad was rotated. This bias did not occur for campus buildings, suggesting that the spatial knowledge gained from navigation was encoded differently from that gained by studying a map. The authors attributed this difference to the learning processes subjects used under each condition. Knowledge gained from maps restricts learning to a single perspective (north at top), but knowledge gained from navigating an environment facilitates learning from several perspectives. Thorndyke and Hayes-Roth (1982) replicated these results in a similar study and proposed that the internal structure used to store the information caused these differences. The authors associated navigational knowledge with propositional encoding because it required remembering a sequence of spatial interactions from a variety of perspectives. Map knowledge, on the other hand, they associated with imagery encoding because it required remembering global environmental properties from a single perspective.

Lloyd and Steinke (1985) investigated the internal representations of spatial knowledge by asking subjects to perform a comparison task using qualitative point symbols plotted on a map or the United States. They divided their subjects into three groups:

1. those that looked at the map while making symbol comparisons (map perception group),

2. those that memorized a map of symbol locations prior to making the comparisons (map memory group), and

3. those that memorized a verbal list of locations prior to making the comparisons (verbal group).

Reaction time responses indicated that the three groups did not differ significantly in their performance of the task. Furthermore, the only variable that significantly affected subject responses was familiarity with state locations, and that variable was significant for all three groups. Because responses for the perception group and memory group were similar, the authors concluded that the memory group was accessing an internal representation similar to the map used by the perception group. They also noted that the significance of the familiarity variable suggested that information about state locations was already stored in memory prior to the testing phase, and that subjects most likely made use of that information in completing the task. The similarity between these two groups and the verbal group (assumed to be accessing a propositional structure), coupled with the significance of the familiarity variable, further suggested that all subjects were using both propositional and imagery structures to complete the task.

More recently, Clayton and Chattin (1989) conducted a study using spatial priming in conjunction with locational judgments. The authors of this study found that previous location tasks significantly affected subject reaction times for locational judgments of campus buildings and U.S. states. When the previous task required subjects to judge locations that were geographically far from the locations in the current task, reaction times increased significantly for that task. Because this effect was absent for the classification of words as states or non-states, the authors concluded that spatial and non-spatial knowledge must be stored in separate internal structures.

Lloyd (1989a) compared distortions in cognitive maps that were encoded and decoded in different ways. Two groups of subjects were tested:

- A navigation group consisted of subjects who had lived in Columbia, South Carolina for at least three years and could describe verbally the locations of landmarks and reference points located throughout the city.

- A map group consisted of subjects who memorized a map of an unfamiliar city with landmarks and reference points.

The cognitive maps of both groups were then tested by asking subjects to locate sets of landmarks for their city using a variety of reference points. Subject reaction times and accuracy rates for these location tasks indicated that the navigation subjects were not able to perform the tasks as effectively as the map subjects. Analysis of the distance and direction errors inherent in the cognitive maps of the two groups of subjects led the author to conclude that the map subjects were using an imagery mode and survey knowledge to complete the tasks; navigation subjects, on the other hand, were thought to be primarily using a propositional mode and verbal procedural knowledge, a form of knowledge representation that would explain the longer access and processing times associated with the locational tasks. Similar results have been reported by Evans and Pezdek (1980) and Thorndyke and Hayes-Roth (1982).

In 1989, Lloyd (1989b) extended his research on the differences between navigational knowledge and map knowledge by further investigating the effects of encoding and decoding processes on cognitive map error. He asked three groups of subjects to estimate distances and directions for routes on a map. Subjects either did this while looking at the map, after a visual training session in which they sketched map routes, or after a verbal training session in which they wrote out verbal directions. Results showed the following:

1. subjects who made the estimates while looking at the map performed the task most efficiently,

2. subjects who completed the verbal training made the largest errors in the estimation tasks, and

3. although verbally-trained subjects displayed larger estimation errors, the pattern of errors was similar for the two groups, suggesting they used similar mental processes to complete the task.

Assessing Cognitive Representations: A New Methodology

Talasli (1990) proposed that the techniques used to assess cognitive representations were vulnerable in two respects:

1. rather than manipulating imagery codes, "they presume the existence of the code, then predict a certain effect of a given manipulation" (Talasli 1990, 404), and

2. the techniques do not test for the simultaneous existence of both propositional and imagery codes.

To overcome these disadvantages, Talasli devised a new methodology consisting of a picture recognition task in which both imagery and propositional codes were simultaneously manipulated at the time of imagery encoding. In his experiment, he asked subjects to study a picture that was presented to them in one of a variety of learning modes. Each learning mode was defined by a combination of grid conditions and scan formats. Under the grid condition, subjects studied either a line drawing with a grid superimposed on top of it or a line drawing without an accompanying grid. Manipulating scan formats allowed subjects to study the line drawing either as a whole picture or as one seen in strips. The presence of a grid over the picture during the study phase was intended to increase the difficulty with which subjects could extract information about the spatial continuity of the picture. Spatial continuity is an attribute of spatial information believed to be encoded using primarily an imagery format (Anderson 1990). Presenting the picture in scanned strips was intended to increase the difficulty with which subjects could extract information about object identities and categorical object relationships. These spatial qualities are primarily associated with propositional encoding (Anderson 1990; Mandler and Ritchey 1977; Kosslyn et al. 1992).

Subjects in Talasli's study viewed the target picture modified by some combination of grid condition and scan format. Following the presentation process, Talasli tested their memories for the presence of both imagery and propositional codes by asking them to perform a series of recognition tasks. To evaluate whether the two codes existed and had been effectively manipulated, he varied object properties within the test pictures used in the recognition task. Object modification was accomplished by using foils, which Talasli defined as changes in the test picture consisting of either the replacement, perspective reversal, or displacement of an object. Object replacement causes problems with both object identification (primarily propositional coding) and spatial continuity (primarily imagery coding). Talasli thus hypothesized that subject detection of a new object that replaced an object in the original picture would tap both imagery and propositional codes if they existed. The effect that grid condition and scan format had on subjects' abilities to detect this change in the test picture indicated whether or not the code had been activated, If, for example, subjects coded such information using both propositional and imagery codes, then both grid presence and picture scanning should interfere with their ability to detect a test picture modified by a new object.

To complement the replacement foil, Talasli designed two more foils:

1. a perspective reversal foil designed to tap primarily imagery codes, and
2. a displacement foil designed to tap primarily propositional codes.

Talasli hypothesized that the reversal in perspective of an object would interfere with the strength of spatial continuity of the picture because perspective changes modify spatial continuity but they do not affect object identity. On the other hand, he believed the detection of object displacements in the test picture would primarily tap propositional codes because displacing an object would modify the categorical object relations in the picture. On the surface, it would also appear that displacement of objects would modify the spatial continuity of the picture as well. Research suggests, however, that complex images are not stored in their entirety but segmented into smaller, more organized units (Kosslyn and Pomerantz 1977). Thus, this type of change should not substantially interfere with the spatial continuity of the picture.

In the recognition tasks, subjects identified a series of test pictures as being either identical to the one they had studied or different from it. Results of the study indicated that subjects used both propositional and imagery codes to complete the picture recognition task. As Talasli hypothesized, picture scanning significantly interfered with subjects' abilities to detect test pictures modified by object displacements and object replacements. Grid presence, on the other hand, significantly interfered with subjects' abilities to detect test pictures modified by perspective reversals and object replacements. These findings led Talasli to conclude that both imagery and propositional encoding exist for pictorial information, and that both types of codes were used and effectively manipulated within his picture recognition task.

Encoding Processes and Cognitive Representations

Spatial Encoding Theories

Both landmark-based learning and path-based learning are theories born of studies that examined spatial knowledge acquisition in an environmental context. Path-based learning proposes that the paths or routes in an environment form the primary framework for spatial knowledge acquisition. After these initial paths are learned, landmarks relative to the paths are coded and stored. Appleyard (1970) was one of the first to provide empirical evidence for this theory. He asked both short-term and long-term city residents to draw sketch maps of their environment. In comparing the maps of the two groups, he discovered that paths dominated the maps of short-term residents, while long-term residents produced more integrated maps that included more landmark information. Devlin (1976) obtained similar results in her study. Other research that supports path-based learning includes studies by Garling et al. (1981) and Peruch et al. (1989).

In contrast to path-based learning, landmark-based learning proposes that landmarks are the basic building blocks of the cognitive map structure. Knowledge of routes is not developed until landmarks have been encoded and stored in memory. Siegal and White (1975) developed one of the first landmark-based models of learning. Their model consisted of three stages:

1. development of landmark knowledge,

2. development of path-based knowledge, and

3. development of integrated, configurational knowledge.

Anchor point theory, proposed by Golledge (1978), is another landmark-based model. He proposes that the cognitive organization of spatial information is hierarchical, with key landmarks anchoring regions of space and serving as endpoints for the paths in the environment. Both Evans et al. (1981) and Okabe et al. (1986) have conducted research that lends support for landmark-based learning.

Encoding Spatial Information from Maps

As MacEachren (1992, 251) succinctly points out,

> Segmentation and focus on subsets of information corresponds to the underlying premise of developmentally based theories Of spatial learning; that learning proceeds from local uncoordinated knowledge to a global coordinated representation.

One early study that examined the use of segmentation as a potential map-learning strategy was Shimron (1978). Subjects in his study learned a map by studying it either in functional map layers or in regionalized subsections. Results of the study indicated that subjects who had learned the map in sections performed memory tests more accurately than subjects who learned the map using thematic layers.

A study by Kulhavy et al. (1982) also suggests that segmentation of spatial information by region is more useful than segmentation by subject category. In their study, subjects were first presented either with a map consisting of a street grid and point features or a map consisting only of point features. Tests of recall indicated that although subjects who studied the map with the grid recalled fewer features, they were able to locate those features more accurately than subjects who studied a map without a grid. In a follow-up experiment, subjects studied a gridded map to which point features were added in incremental stages. The presence of point features for each group was defined differently. For the first group, point symbols were presented in thematic or topical stages; the second group saw spatially segmented stages of symbols, and the third group saw randomly segmented stages of symbols. The authors found no significant differences among the three groups, indicating that the grid structure of the map was more important in learning spatial information than the segmentation of information by some other means.

MacEachren (1992) investigated the potential of landmark-based and path-based learning for encoding spatial information from maps. Both of these theories result from examining how humans interact with their environment over time. Since these theories address the process of spatial knowledge acquisition, however, it seems logical to assess their utility for explaining spatial knowledge acquisition in a map environment as well. MacEachren designed a map that could be presented to subjects under four different conditions:

1.. landmark-based strategy,

2. path-based strategy,

3. region strategy, and

4. whole-map strategy.

Because he dealt with an information structure created from a two-dimensional graphic and not a three-dimensional environment, MacEachren hypothesized that strategies based on learning landmarks first or paths first might not be as effective for map learning as a strategy in which individual regions of the map were learned incrementally.

After assigning each subject to a particular presentation strategy group, MacEachren had subjects memorize the map presented to them. They then performed a series of distance and direction estimates using their cognitive map of the area. Results of the study indicated that subjects who used a path-based strategy to memorize the map memorized it more efficiently and more accurately than subjects in other groups. Subjects in the whole map group completed the direction estimates significantly faster, however. The whole map group was also fastest at completing distance estimates, but the effect was not significant. The author did not find any significant differences in accuracy rates between any of the groups.

An interesting interaction effect in MacEachren's study—and one that is particularly relevant to this study—concerns Group Rotation. "Group" pertains to the strategy subjects used to learn the map, and "rotation" designates the subject as one who either rotates a map when traveling or one who does not. For both distance and direction estimates, subjects in the path-based strategy group who classified themselves as map rotators performed the tasks faster than rotators in other groups. MacEachren concluded from these findings that those who were not as adept at visualizing found the experimental tasks more difficult unless they had learned the map using a strategy that promoted propositional encoding. Task completion for rotators was facilitated when they used a path-based strategy to learn the map; this led the author to infer that the path-based strategy enhanced the propositional coding of spatial information. An examination of error for group x rotation provided MacEachren with further evidence to support this theory. Rotators in the path-based strategy group had significantly larger distance errors than non-rotators in the group, an effect that was absent for all other groups. Lloyd (1989b) showed that subjects who verbally encoded a map made larger distance errors than subjects who used imagery to encode the map.

Experiment

This study integrated MacEachren's (1992) path-based and landmark-based strategies with Talasli's (1990) method of assessing the mental representation of knowledge. The replacement of Talasli's (1990) sequential and random scan formats with MacEachren's (1992) path-based and landmark-based strategies strengthens the methodology for a map-based task. Spatial information is not learned in a random or sequential fashion, but it may be learned in fragments similar to those that make up the theories of landmark-based and path-based learning. Furthermore, these learning processes serve to fragment the map being studied, just as Talasli's scan formats fragmented his line drawing. Thus, they should serve equally well in interfering with propositional code formation. By combining elements of Talasli's (1990) and MacEachren's (1992) research, it was possible to:

1. provide an alternative means of assessing the existence of propositional and imagery codes within a single map task; and

2. examine how encoding processes affected the final cognitive representation of that information.

Subjects

A total of 180 subjects, recruited from the student body of the University of South Carolina, participated in this research. Subjects consisted primarily of undergraduate and graduate students at the university. Subjects received either monetary compensation or extra credit for courses in participating geography and psychology classes.

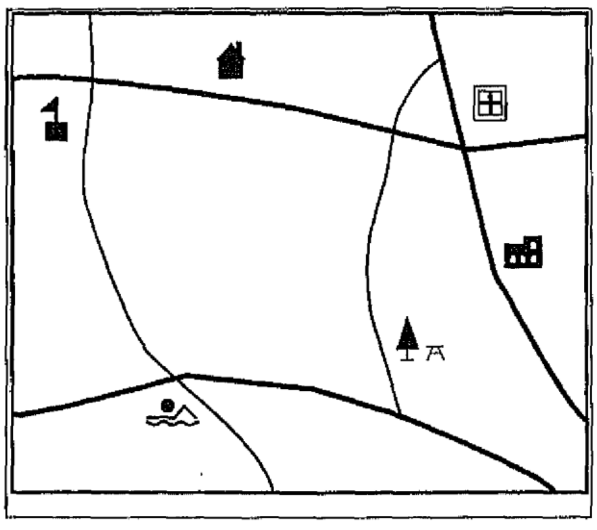


Figure 1. Target map.

Learning Mode	Grid Condition: Grid Absent	Grid Condition: Grid Present
Static Map	N	I
Landmark-based	P	IP
Path-based	P	IP

N = No interference with codes
I = Imagery code interference
P = Propositional code interference
I P = Interference with both codes

Table 1. Experimental test groups and hypothesized code interference.

The Target Map

The target map used in the experiment consisted of a simple street pattern and pictorial landmarks, and was presented in black and white on a computer screen (Figure 1). The map was designed to fit onto the screen so that map features were represented clearly and legibly. Verbal labels were excluded from the map to provide control over experimental variables.

The Test Groups

Subjects were divided into six groups, where each group was defined by the combination of the target map's learning mode and grid condition (Table 1). Three learning modes, designed to manipulate how subjects acquired spatial information, were modeled after those MacEachren used in his 1992 study. The static map test groups served as the control mode; subjects who studied the target map using this learning mode saw it as a static representation that remained on-screen for three minutes (Figure 1).

Subjects assigned to the landmark-based test groups studied a series of seven separate map segments designed to emulate the theory of landmark-based learning. Segment presentation was controlled by computer; each segment was displayed briefly before being replaced by the next segment, and succeeding segments were built on information presented in the previous displays. For example, the first segment in the landmark-based cycle (displayed for three seconds) consisted of three primary landmarks (Figure 2a). Following this segment, the computer displayed three more segments, where each segment consisted of one of the primary landmarks along with a secondary landmark (Figures 2b-2d). These segments were also displayed for three seconds each. The last three segments, presented for six seconds apiece, each consisted of a pair of primary landmarks along with secondary landmarks and connecting roads (Figures 3a-3c). The entire cycle lasted for 30 seconds, and landmarks were presented more frequently than roads in the presentation process. Subjects studied this presentation cycle six times for a total of three minutes, which equaled the amount of time subjects in the static map test group spent studying the target map.

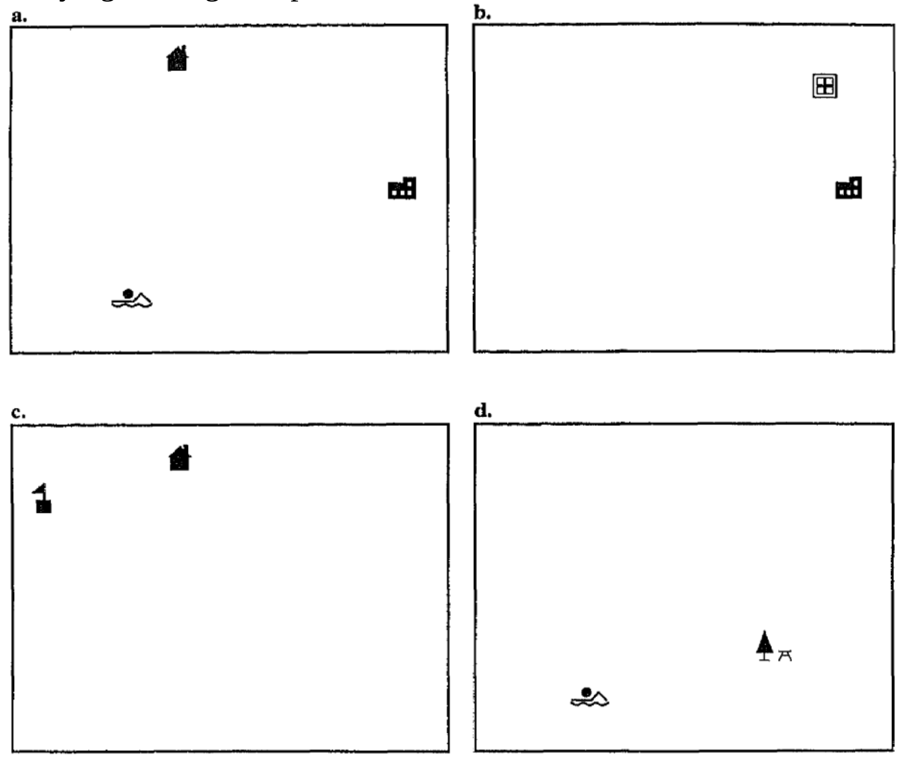


Figure 2. Landmark-based learning, segments 1-4.

Subjects assigned to the path-based test groups experienced a similar process, except that the segments used in these groups emulated path-based learning (Figures 4 and 5). These learning modes served as variants of Talasli's (1990) scan format. The results of Talasli's study indicated that fragmentary learning processes interfered with the formation propositional codes. Since both landmark-based learning and path-based learning are fragmentary processes, it is hypothesized that they should also interfere with propositional code formation, especially since the entire map is never seen as one coherent representation.

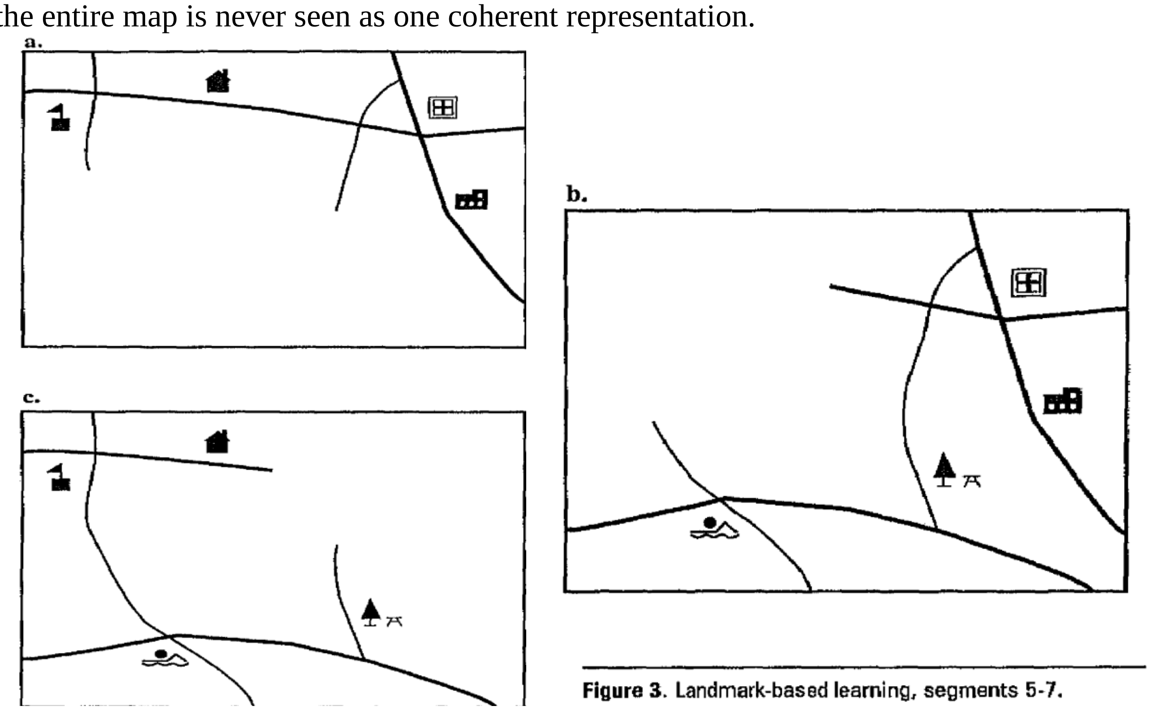


Figure 3. Landmark-based learning, segments 5-7.

Subject test groups were also defined upon the basis of a grid condition. Essentially, groups either studied a target map without a grid (Figure 1) or with a heavy grid superimposed on top of it (Figure 6). The grid condition was modeled after Talasli (1990), who showed that grid presence interfered with remembering the spatial contours of a picture. The grid for this study was designed to match the specifications of Talasli's grid; it consisted of horizontal and vertical lines approximately 1 mm (0.04 in) thick and spaced approximately 1.5 cm (0.59 in) apart.

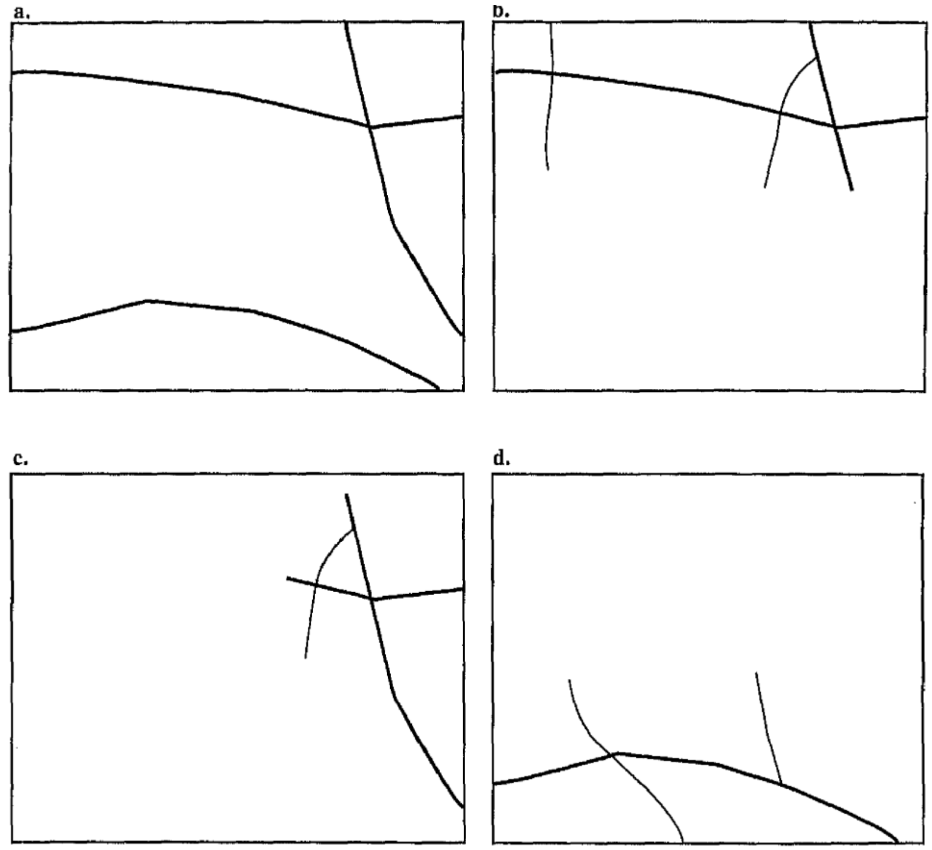


Figure 4. Path-based learning, segments 1-4.

The Task

After randomly assigning a subject to a test group, the task administrator instructed the subject on the steps of the experiment. Subjects then participated in a practice session using a practice map to further familiarize themselves with the process. The test procedure consisted of two phases: in the first phase, each subject studied a target map that was presented to them by computer. Map presentation corresponded to the learning mode and grid condition of the subject's test group. Following this presentation, each subject viewed a series of test maps and was asked to determine whether each map was identical to or different from the target map they had just studied.

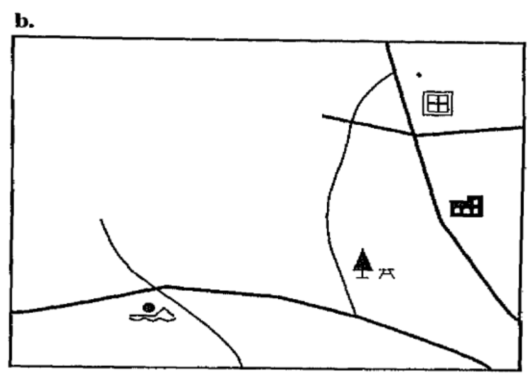
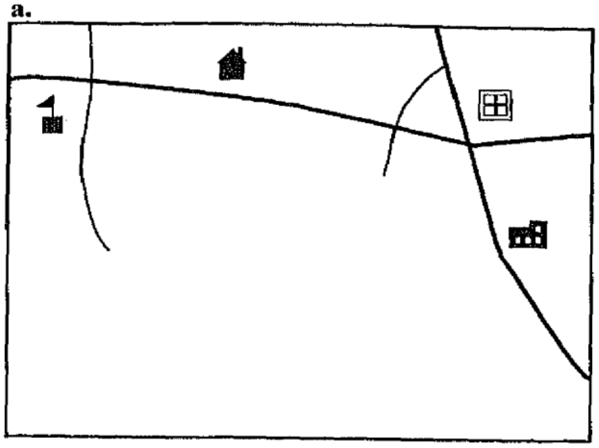


Figure 5. Path-based learning, segments 5-7.

The test maps that differed from the target map were modified by using one of three foils. These foils, which were modeled after those used by Talasli (1990), can be best described as changes in the target map consisting of either the replacement, perspective reversal, or displacement of an object. The purpose of these foils was to test the effectiveness of grid presence and fragmented learning modes in interfering with the detection of these changes (Table 2). Talasli's research (1990) showed that grid presence interfered with the detection of changes in the spatial continuity of the picture, an imagery-related attribute. Thus, it was hypothesized that foils coded using primarily imagery codes (i.e., object replacements and perspective reversals) would be harder to detect when a grid was present during map learning. Likewise, foils primarily coded using propositions should be harder to detect when subjects study a map using a fragmented mode, Talasli (1990) showed here that fragmentation interfered with the detection of object identities and object relations, propositionally related attributes.

a.



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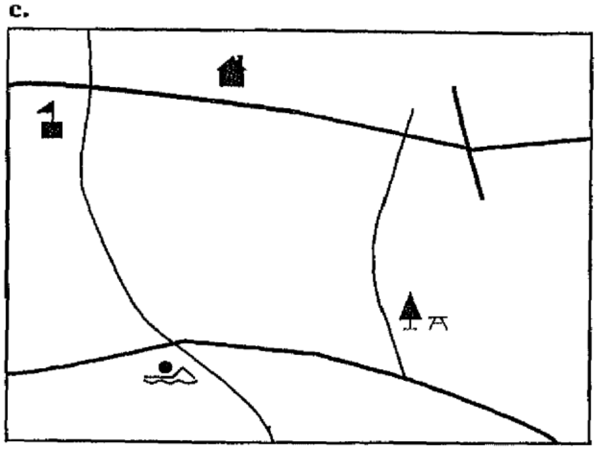

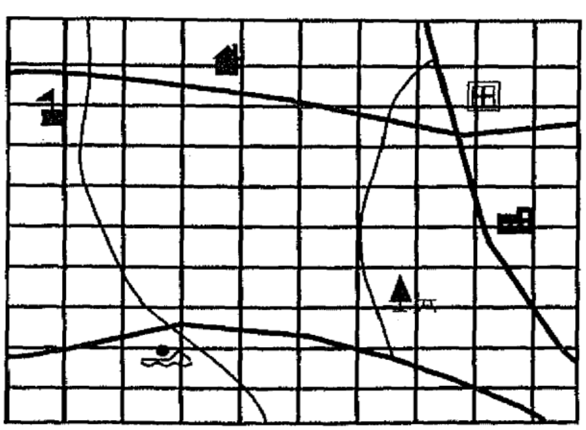

Figure 6. Target map with grid.

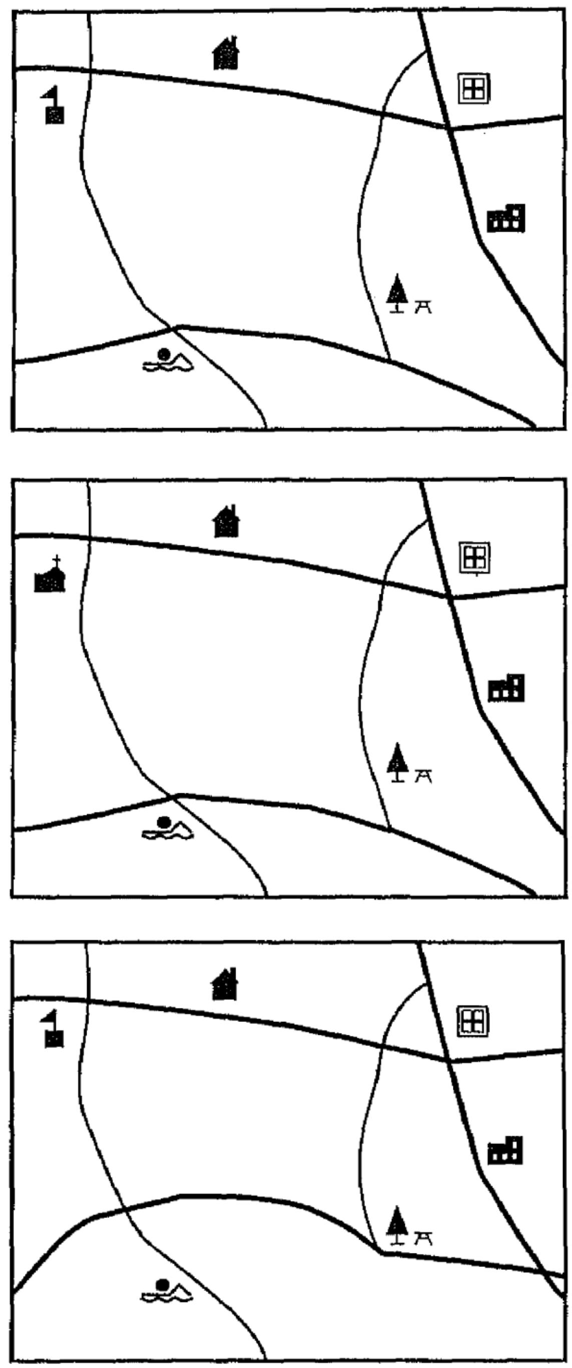

Figure 7. Target map (top), test map with replacement symbol foil (middle), and test map with replacement road foil (bottom).

Replacement Foils
A replacement foil is a new object that replaces an object on the target map to make a test map.

Objects that could be replaced included both landmarks and roads. These foils were designed to be thematically-related to the objects they replaced (i.e., replacing a park symbol with a forest symbol), as well as visually similar to the original object (Figure 7). Because a replacement foil changes object identity as well as the spatial continuity of the map, detection of this foil should be hampered both by grid presence and by studying the map using a fragmented learning mode. Thus, subjects in test groups that used fragmented learning or a grid in studying the target map should have more difficulty detecting test maps modified by these foils than subjects in other test groups (Tables 1 and 2).

Codes Tapped (✓)	Foil Type: Replacement	Reversal	Displacement
Propositional	✓		✓
Imagery	✓	✓	

Table 2. Foil types and code formats.

Reversal Foils
A reversal foil is an object on the test map that is reversed in perspective from the object on the target map (Figure 8). Both landmarks and roads could exhibit this effect, to differing degrees. Alternating the perspective of a landmark was accomplished by constructing a mirror-image of the symbol. Perspective reversals of roads required a somewhat different strategy. Because roads are connected to one another and have the attribute of length, constructing a mirror-image of a segment destroyed the overall network of road connections. Therefore, to achieve a reversal-like effect, road width was alternated from thin to thick or thick to thin. Reversal foils cause changes in the spatial continuity of the map, but they do not affect object identities or object relations. Thus, the detection of maps modified by these foils should be hampered only by grid presence. Subjects in test groups where a grid is overlaid on the target map should have more difficulty detecting test maps modified by these foils than subjects in groups where the grid is absent (Tables 1 and 2).

Displacement Foils
An object on the test map that is moved in relation to the same object on the target map is called a displacement foil (Figure 9). Landmark displacement foils were displaced so that only relations to other landmarks were violated; relations between these foils and the road network always remained intact. Conversely, road displacement foils were displaced so that relations to landmarks remained intact, but relations to the road network were violated. Both types of displacement foils cause changes in object relations, so test maps modified by these foils should be more difficult to detect when subjects study the map using a fragmented learning mode (Tables 1 and 2).

Subject Responses
For each test map presented, subjects indicated whether the test map was the same as or different from the target map they had originally studied. Subjects responded to each map by pressing the appropriate key on the computer keyboard to record their answer. The dependent variable used in this study was the percentage of correct responses. Each subject completed 48 map recognition trials; 24 maps were identical to the target map studied and 24 maps differed from the target map. Of those maps that differed, 12 were modified by changing a

landmark (four replacement foils, four reversal foils, four displacement foils) and 12 were modified by changing a road (four replacement foils, four reversal foils, four displacement foils).

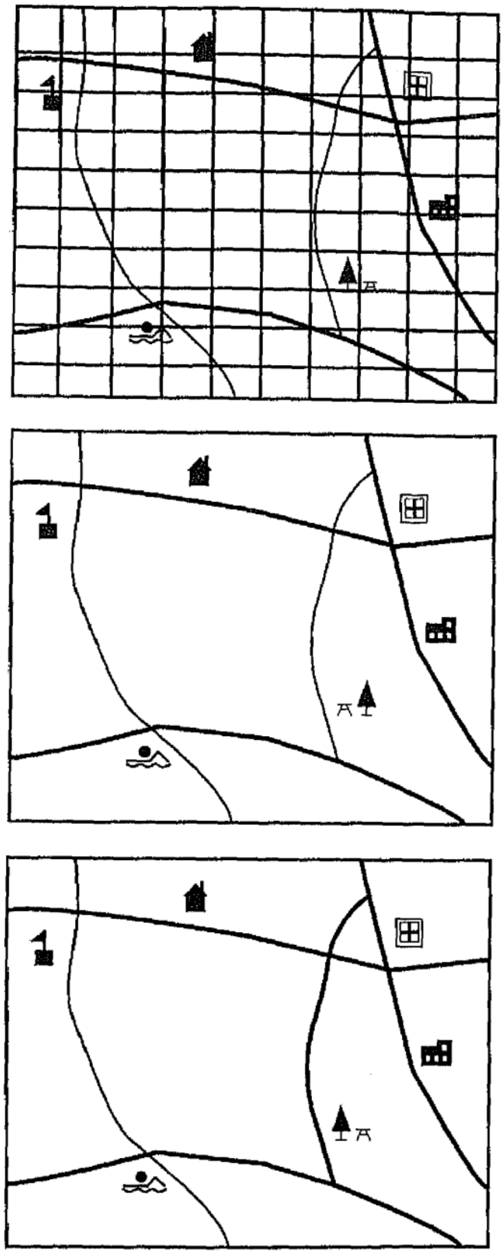

Figure 8. Target map (top), test map with reversal symbol foil (middle), and test map with reversal road foil (bottom).

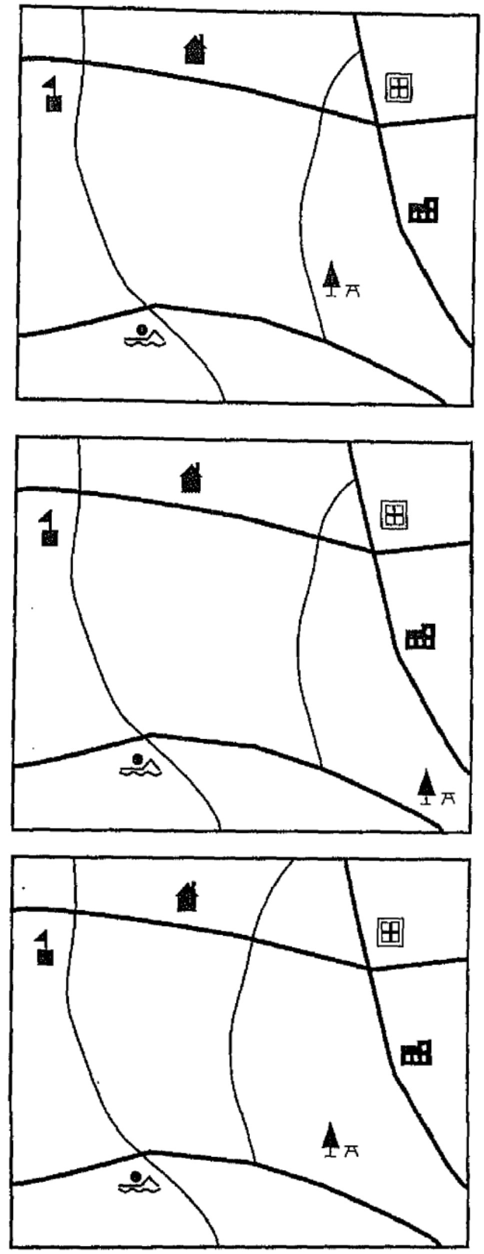

Figure 9. Target map (top), test map with displacement symbol foil (middle), and test map with displacement road foil (bottom).

Hypotheses

1. Subjects in the landmark-based and path-based test groups should respond to the recognition task significantly less accurately than subjects in the static map test groups. The fragmented nature of these learning modes should interfere with subjects' abilities to encode spatial information in a general sense (Table 1).

2. Subjects in test groups where a grid was superimposed on the target map should respond to the recognition task significantly less accurately than subjects in test groups where the grid is absent (Table 1). Grid presence adds information to the map, and in this case the extra information should act as a detractor because of the grid's spacing and line width. Thus, grid presence should not facilitate task completion, but rather interfere with subjects' general abilities to encode spatial information.

3. Subjects in the landmark-based and path-based test groups should have significantly more trouble detecting test maps modified by replacement foils and displacement foils than subjects in the static map groups (Tables 1 and 2). Detection of test maps modified by replacement and displacement foils should primarily activate propositional codes, and fragmented learning modes should interfere with propositional code formation (Talasli 1990). Furthermore, research conducted by MacEachren (1992) suggests that path-based learning may encourage the propositional encoding of spatial information in comparison to landmark-based learning. Thus, it is further hypothesized that subjects in the path-based test groups should have significantly less trouble detecting test maps modified by replacement and displacement foils than subjects in the landmark-based test groups (Tables 1 and 2).

4. Subjects in test groups where a grid was superimposed on the target map should respond significantly less accurately to test maps modified by replacement foils and reversal foils than subjects in test groups where the grid is absent (Tables 1 and 2). Detection of test maps modified by replacement and reversal foils should require primary activation of imagery codes, and grid presence should interfere with imagery code formation (Talasli 1990).

Analysis and Results

The data for the dependent variable (accuracy rates) were aggregated over all subjects and across all variables to minimize data abnormalities. Only "different" maps were considered in the analysis because the focus of this study was on subjects' abilities to detect test maps modified by various foils, The accuracy data were analyzed using a general linear model (GLM) analysis of variance (ANOVA). The main effects for each model were learning mode (three levels), grid condition (two levels), foil type (three levels), and component type (two levels). All possible interactions were analyzed. The model was significant [F(26,261)-7.72, P>F=.0001] and explained 43% of the variance in subject accuracy rates (Table 3). Three main effects and one interaction effect reached significance in the analysis.

Independent Variable	DF	F Value	P>F
Learning Mode	(2,285)	7.32	.0008
Grid Condition	(1,286)	1.25	.2644
Foil Type	(2,285)	31.58	.0001
Component Type	(1,286)	15.47	.0001
Learning Mode x Foil Type	(4,279)	0.78	.5399
Grid Condition x Foil Type	(2,282)	0.04	.9635
Learning Mode x Component Type	(2,282)	0.99	.3712
Grid Condition x Component Type	(1,284)	0.65	.4202
Component Type x Foil Type	(2,282)	47.01	.0001
Grid Condition X Learning Mode	(2,282)	0.55	.5789

Table 3. General linear model with accuracy rate as the dependent variable (R^2=0.43).

Learning Mode

As Figure 10a shows, subjects in the path-based groups were considerably less accurate in detecting modified test maps than subjects in either the landmark-based groups or the static map groups. Differences between subjects in the static map groups and the landmark-based groups were less striking. As expected, analysis of this variable confirmed that learning mode played a significant role in subject responses [F(2,285)=7,32, P>F=.00081, Post hoc comparisons of the means indicated that accuracy rates for the static map groups did not differ significantly from those for the landmark-based groups [T(190)=1.14, *P>T= .2556]*. Subjects in the path-based groups, however, were significantly less accurate than subjects in both the static map groups [T(190)=3.73, .0002] and the landmark-based groups [T(190)=2.59, *13*>T=.0100].

An examination of the interaction of learning mode x foil type (Figure 10b) indicates that subjects in the path-based groups had more difficulty in detecting test maps modified by reversal and displacement foils than subjects in the other test groups. Contrary to expectations, this interaction effect was not statistically significant [F(4,279)=0.78, P>F=.5399]. A post hoc comparison of means showed, however, that subjects in the path-based groups were significantly less accurate in detecting test maps modified by displacement foils than subjects in the static map groups [T(62)=2.79, *P>T*= .0056]. They were also less accurate than subjects in the landmark-based groups [T(62)=1.85, *P>T= .0660*], although this comparison of means was only marginally significant, A similar, but unexpected result was obtained for reversal foils.

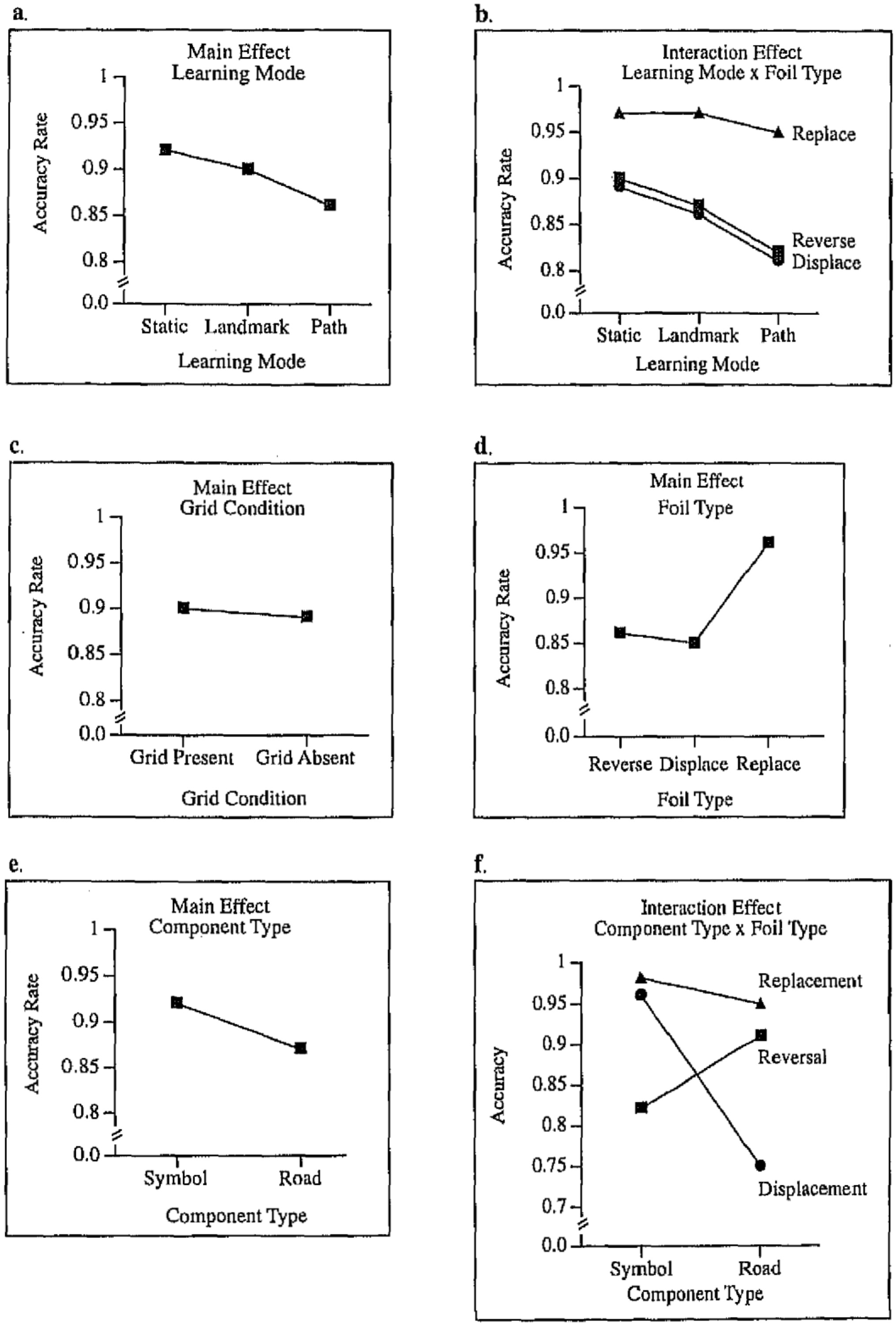

Figure 10. Results of accuracy rate analysis. Each graph shows how a main effect or interaction effect was related to accuracy.

Grid Condition

The graph showing the relationship of grid condition and accuracy rates (Figure 10c) indicates that subjects who studied the map with a superimposed grid were no less accurate in detecting modified maps than subjects who studied the map without a grid. Results of the ANOVA confirmed that grid condition (contrary to the hypotheses) was not a significant factor in explaining the variation in accuracy rates [F(1,286)=1.25, P>F=.2644]. Furthermore, grid condition did not significantly interact with foil type, as expected, or with any of the other independent variables (Table 3).

Foil Type

Figure 10d shows that test maps modified by replacement foils were much easier to detect than those modified by reversal foils or displacement foils. ANOVA results confirmed that foil type was a significant effect [F(2,285)=31.58, P>F=.0001], indicating that the types of foils subjects were asked to detect played a role in explaining the accuracy of their responses. Post hoc comparison of means for the three foils indicated that subjects were significantly more accurate in detecting test maps modified by replacement foils than either reversal foils [T(190)=6.59, P>T=.0001] or displacement foils [T(190)=7.14, *P*> T=..0001], Accuracy rates for detecting test maps modified by reversal foils were not significantly different from those modified by displacement foils [T(190)=0.55, P>T=.5833].

Component Type

Examination of Figure 10e indicates that component type also influenced how accurately a subject responded to the map recognition task. Subjects seemed to find detecting test maps modified by symbol changes (landmark foils) much easier than detecting test maps modified by changes in roads (road foils). Analysis of this variable showed that the difference these two types of changes had on accuracy rates was significant [F(1,286)=I5.47, P>F=.0001].

Component type also interacted significantly with foil type [F(1,282)=47.01, P>F=.0001]. As Figure 10f shows, subjects found test maps modified by displacement foils easier to detect when the change was made to a symbol. Conversely, they found test maps modified by reversal foils easier to detect when the change was made to a road.

Post hoc comparisons confirmed that the reversal foil means for symbol changes and road changes were significantly different [T(94)=4.03, *P>T*= .0001], as were the means for displacement foils [T(94)=9.57, *P>T*= *.0001*].

Discussion

Results of this study offer insights about:

1. how spatial knowledge is mentally structured, and

2. how encoding processes influence that structure.

Subjects, divided into six test groups, studied a target map that was presented to them using a combination of learning mode (static, landmark- based, path-based) and grid condition (grid absent, grid present). Following the study period, subjects' mental representations of the target map were evaluated using a map recognition task.

When subjects studied the target map using either the static map or landmark-based learning mode, they detected modified maps significantly more accurately than subjects who used the path-based learning mode to study the map. Such results suggest that landmark-based learning and anchor point theory (Golledge 1978) transfer well from an environmental context to a map context, at least when the task is to recognize changes in a mapped area. Path-based learning, on the other hand, does not seem to make the transition as effectively.

These findings stand in contrast to MacEachren (1992), who found that path-based strategies:

1. facilitated map learning, and

2. were more effective than landmark-based strategies for completing distance and direction estimates.

It is possible that differences in the design and presentation of the experimental maps play a role in producing these contrasting results. The number of streets and landmarks on MacEachren's maps were unbalanced, with the maps having more streets. Thus, subjects using a path-based strategy to learn the map were initially exposed to more information than subjects using the landmark-based strategy, a situation that was avoided in this study. MacEachren also included verbal information on his maps, a component this study omitted in order to restrict the propositional encoding of information to spatial objects. Furthermore, all subjects in MacEachren's study saw the map in its entirety at some point during the simulation process. In this study, only subjects who studied the map using the static map learning mode saw the map in its entirety. Since landmark-based and path-based learning do not include holistic encounters with the environment as part of the learning model, subjects using either of these learning modes were not exposed to such a display.

Another equally plausible explanation is that the different task requirements of the two studies played a role in which types of encoding processes worked best. MacEachren's distance and direction estimates are linear tasks and may be better matched to an encoding process that emphasizes linear components. With the map recognition task, subjects were searching for changes to isolated objects on the map; perhaps a task such as this is better matched to an encoding process that emphasizes point locations.

Of the three types of foils that could modify a test map, only the detection of test maps modified by displacement foils and reversal foils was significantly affected by learning mode. When subjects studied the target map using the path-based learning mode, their detection of test maps modified by these foils was significantly less accurate than those of subjects who studied the map using either the static map or landmark-based learning modes. This suggests that the path-based learning mode interfered with subjects' abilities to encode both categorical object relations and spatial continuity. In theory, this learning mode should have interfered with the detection of test maps modified by displacement foils and replacement foils, but not reversal foils.

The lack of interference in detecting test maps modified by replacement foils is clearly explained by examining the effect of foil type on subject responses. Subjects in all test groups found test maps modified by replacement foils significantly easier to detect than those modified by displacement and reversal foils. Given that replacement foils were designed to be both visually and conceptually similar, the near ceiling performance of subjects in detecting test maps modified by these foils is striking. This anomaly also suggests why the variance for the overall model is so low. A secondary analysis that breaks the variables of component type and foil type down into their constituent parts shows that much of the variance not accounted for in this analysis can be explained by differences in individual map trials. Why was it so much easier for subjects to detect test maps modified by replacement foils as opposed to those modified by displacement or reversal foils? Perhaps the landmark-based and path-based learning modes did not interfere as severely with object identity coding as Talasli's scan formats. In his study, the scanning of the target picture in strips caused some objects to be fragmented by the scan boundaries. In this study, the landmark-based and path-based learning modes replaced Talasli's scan formats. While these learning modes allowed the map to be presented in logical segments, they did not allow (as did Talasli's scan formats) fragmented map objects, except in the 'case of presenting the road network in multiple sections.

The significant interaction of the path-based learning mode with reversal foils is not as easily explained. Reversal foils, according to Talasli's (1990) results, should be coded primarily by using imagery codes, and imagery coding should not be affected by varying the learning mode under which the map is studied. For Talasli's scan formats this may have held because subjects saw every part of the picture an equal amount of times during the scan process. For the path-based and landmark-based learning modes, however, this was not the case. In the path-based learning mode, subjects were first exposed to individual road segments, then to those road segments as they were connected to other roads, and finally to partial road networks with interspersed landmark symbols. Subjects, then, were exposed less to landmarks, which could have prevented the coding of symbol perspectives altogether. This explanation does not, however, account for subjects' greater difficulties in detecting test maps modified by reversal foils for roads. Perhaps subjects perceived a road reversal, which consisted of alternating the thickness of a line, as a new road or replacement symbol. If this hypothesis is true, then road reversals could have been coded using either imagery or propositions.

The finding that only path-based learning significantly interfered with the detection of test maps modified by displacement and reversal foils further suggests that this mode interfered more with the propositional encoding of spatial information than the landmark-based learning mode. Perhaps organization by pictorial landmark positions did not interfere as much with propositional encoding because the landmarks were easily differentiated, making symbol identities and their relative locational positions less of an effort to remember. The path-based learning mode used in this study, on the other hand, would not have had such an advantage. Individual road segments were not easily differentiated graphically, possibly making their identities and relative locational positions more difficult to encode.

These results again contradict MacEachren's (1992) findings, which suggested that path-based strategies encouraged the use of propositional encoding for poor visualizers. The findings of these two studies may have differed simply because MacEachren based his conclusions about path-based strategies on a subset of his subjects, poor visualizers. Analysis of the path-based learning mode in this study did not differentiate subjects on that basis. Equally plausible is that the differences in the findings between the two studies stem from the dependent variables upon which the conclusions were based. MacEachren (1992) suggested that a path-based strategy facilitated propositional encoding because poor visualizers performed distance and direction estimates significantly faster when they learned the map using that encoding process. He found no significant differences in the accuracy rates among the different groups. When subjects in this study studied the map using the path-based learning mode, accuracy rates were much lower for those subjects than for subjects who studied the map using the other learning modes. Thus, this study's results suggest that path-based learning interferes more with propositional coding than landmark-based learning, at least when the task emphasizes recognition of point locations and accuracy rates are the primary performance measures.

None of the subject responses recorded for the map recognition task were significantly affected by grid presence. Thus, unlike Talasli's (1990) study, the presence of a grid during map learning failed to interfere with the formation of imagery codes. Why would grid presence work as predicted for a picture recognition task, but fail to produce comparable results for a map recognition task? Perhaps it is due to the role a grid plays when it is added to either a picture or map. The presence of a grid over a landscape scene is unexpected and could be considered disruptive, but the same grid over a map might be viewed as an expected and even useful component. The grid in this case would not necessarily degrade the processing of spatial information, but instead might even serve to enhance and organize that information. Kulhavy et al. (1982), for instance, found that subjects who studied a map with a grid were able to locate recalled features more accurately than subjects who studied a map without a grid. Results of this study, although not significant, also suggested that grid presence enhanced the accuracy and confidence of subject responses.

Subject performance of the map recognition task also depended on the type of spatial component manipulated. Subject responses for all test groups were significantly less accurate when the test map manipulated a road component. Furthermore, component type also affected subjects' responses to the various foil types differently. Subjects detected test maps modified by reversal foils significantly more accurately when the spatial component reversed was a road. Conversely, they detected test maps modified by displacement foils significantly more accurately when the component displaced was a symbol. Talasli (1990) offers no precedent for this, because he worked only with landmark manipulations in his study. By their very nature, however, the pictorial landmarks and street segments on the map presented considerably different types of graphic information. Symbols were easily recognizable, isolated objects; roads, on the other hand, were graphically abstract and were most likely perceived as an integrated network of segments rather than as isolated lines. If the roads were seen as a network, then the displacement of a road would have been less perceptible than the displacement of a symbol, especially since road displacements only violated road relationships. The difference in responses to reversal foils may lie in the way reversals were implemented for symbols and roads. For symbols, perspective reversal was accomplished by producing a mirror-image of the symbol; for roads, segments were reversed by alternating line thickness to approximate a reversal characteristic. Perhaps the alternation of line thickness was easier to detect than mirror-images of symbols.

Conclusions

This research adds to spatial cognition findings that have been building over the last decade or so in cartography. Results of the study suggest that subjects were encoding at least some of the map's spatial information propositionally, confirming the results of Talasli's (1990) work with line drawings, In contrast to MacEachren's (1992) research, however, subject performance in this study suggests that the path-based learning mode interferes more with the ability to accurately encode information propositionally than the landmark-based learning mode. In fact, general subject performance was worst for those subjects in the path-based test groups. This suggests that this method of encoding, at least for recognition tasks that emphasize point locations, may pose disadvantages for completing the task with high levels of accuracy. Subjects who studied the map using the landmark-based learning mode, on the other hand, produced responses that did not differ significantly from subjects who studied the map using the static map learning mode. It might be hypothesized, then, that landmark-based learning is a viable map encoding alternative given this comparability in levels of accuracy for task responses. Of course, additional research is needed before such a hypothesis could be fully accepted. For instance, it would be particularly interesting to assess the applicability of these encoding processes for a variety of map reading tasks, as well as for encoding a variety of map types.

Using grid presence or absence to manipulate the formation of imagery codes did not work as well as originally predicted. This failure to detect the formation of imagery codes in the encoding process is not, however, a declaration that imagery encoding is nonexistent. Rather, it seems more likely that the inability to detect such codes resides in the design methodology of this study, especially since Talasli (1990) received such different responses in a similarly designed experiment. Future extensions of this research might include revising the grid density or perhaps devising some means other than a grid to manipulate the ease of forming imagery codes in a map-based task environment.

The significant influence of component type on subject responses creates several new questions for cartographers in the realm of spatial cognition. Maps consist of multiple graphic elements; the suggestion that they may be processed differently indicates a need to assess how the map reader interacts with each of these element types. Research that investigates the mental processing of map elements, both individually and as a complete spatial unit, may shed more light on this finding.

Cartographers still have much to do to unravel the nature of cognitive processing as it relates to the acquisition, storage, and use of spatial information. The results of this study represent a Stepping stone in that direction. The rapid growth of computer technology has spawned several new ways of displaying and manipulating spatial data. A more comprehensive understanding of the mental processes used in interpreting and analyzing spatial information is essential if we hope to adopt and exploit this technology successfully.

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