Human Factors in GIS Use: A Review and Suggestions for Research

Tonda Bone
tbone@unt.edu
School of Library and Information Sciences, University of North Texas
Denton, TX 76203, USA

Dena Johnson
djohnson@tarleton.edu
Computer Information Systems, Tarleton State University
Stephenville, TX 76402, USA

ABSTRACT

Geographic information systems (GIS) are becoming ubiquitous tools for constructing, manipulating, and communicating spatially-referenced information. Their use in problem-solving, management, and educational contexts is expanding to permeate social environments and the realm of public citizenry. While a GIS can visualize information in a number of ways, maps are the most common form for communicating information. Many studies have explored the effects of spatial ability on map reading, but little has been done in the way of delimiting key human factors that mediate an individual's use of a GIS to solve spatial problems. This research reviews literature from geographic, cognitive, information systems, and decision sciences in order to establish important areas of research for understanding how users interact with a GIS. Understanding the effect of these individual factors on GIS interaction will mediate how educators teach GIS and incorporate it as course tool, how designers approach system development, how geodatabase administrators manage spatial data repositories, and how managers incorporate the human (employee) element into the spatial data work flow.

Keywords: geographic information systems; human factors; spatial cognition; spatial ability; computer aptitude; mental models

1. INTRODUCTION

The purpose of an information system is to assist users with satisfying an information need. In a classic article, Mason and Mitroff (p. 39) defined information systems as consisting of "at least one person of a psychological type who faces a problem within some organizational context for which he needs evidence to arrive at a solution (i.e., to select some course of action) and that the evidence is made available to him through some mode of presentation" (p. 475). A geographic information system (GIS) provides tools for collecting, managing, integrating, analyzing, and displaying data that is spatially referenced. This includes representations of locations, as well as non-spatial data (attributes) that describe those locations. GIS technology embraces "all forms of digital analysis, manipulation, querying, communication, retrieval, and output" (Goodchild, Egenhofer, Kemp, Mark, & Sheppard, 1999, p. 736); it is used to solve problems containing a spatial component. As a spatially-referenced information system (Turk, 1990), a GIS thus extends Mason and Mitroff's information system definition by adding a spatial component to the "problem" and "evidence" aspects of system interaction.

In addition to environmental science applications, GIS implementation is evidenced in agriculture (e.g., precision farming), public administration (e.g., water infrastructure maintenance), business (e.g., site selection), and education (e.g., science and social studies), to name but a few. However, as with other information systems, GIS are fully utilized only if they meet the information needs of their users. Thus, it is imperative that system designers understand the human factors that inform the use of a GIS to create, manipulate, and communicate information for problem solving and decision making. As well, educators also must recognize the mediating effect that students' cognitive styles and abilities have on learning to design and to use a GIS. Understanding the role of human factors is particularly important in education, as GIS is current in the curriculum not only as a system for students to design, but also as a system from which students learn and use for decision making. The classic GIS framework consists of data, hardware, software, procedures, and people (Harmon & Anderson, 2003; Turk, 1990). While each component of the GIS framework is related, this paper will focus on the human variable. In particular, through an analysis of the literature, we will distill key human factors that impact a user's interaction with a GIS. The paper will close with a discussion of suggested research agendas.

2. HUMAN FACTORS

The literature streams within GIS, management information systems (MIS), spatial cognition, and cartography indicate numerous human factors influencing interaction with a spatial information system. This study examines literature investigating geographic spatial cognition and human factors implicated in GIS interaction, so other relevant factors (such as learning preferences or personality style), have necessarily been excluded. Such factors include issues of technology acceptance and of cognitive factors including personality style, learning preferences, and field dependence/independence. While relevant to human-computer studies in GIS, these topics are left for future examination.

Nyerges (1993) sets forth a list of psychological factors impacting GIS use, the majority of which are echoed throughout the geographic information and spatial cognition literature: "spatial ability, spatial knowledge retention, problem-solving ability, the ability to employ mental strategies for problem solving [mental models], the degree of cognitive control of mental strategies for problem solving, and skill of tool use" (p. 38). Rasmussen, Pejtersen, and Schmidt (1990) describe cognitive control to be indicative of an individual's familiarity with the problem domain; Nyerges (1993) associates this fluency with cognitive effort.

The body of literature examined here coalesces around similar factors. Particularly, the key human attributes impacting GIS reduce to these primary factors: gender differences in spatial cognition, spatial ability, map reading aptitude, cognitive mapping, and mental models and problem solving. To a much lesser extent, the literature also examines computer aptitude and computer self-efficacy. Though an interesting (and, one might assume, obvious) consideration as a factor of influence, cognitive style was not studied in the bulk of the literature presented here. For example, we located only one (MIS) study which examined the effects of a user's need for cognition (NFC) on GIS interaction. However, each of these primary factors, including NFC, will be considered in more detail in the following sections.

Gender

The focus of this project is to identify key cognitive factors that impact the user or designer's interaction with a GIS. Gender-related difference in spatial ability is a key underlying theme in many human-factor studies. The discussion of cognitive differences due to gender – whether biological or socio-cultural – is extensive, and full coverage is beyond the scope of this paper. However, it should be noted that studies have cast doubt on the general acceptance of a male superiority regarding spatial ability (Vincent, 2004), particularly because/when the spatial tasks have been narrowly defined (Montello, Lovelace, Golledge, & Self, 1999). For example, Gilmartin and Patton (1984) found that, on map use skills involving "route planning, symbol identification, visual search and estimation, and right/left orientation" (p. 605), male and female college students performed equally well. In a test of route acquisition via learning from a map or from a computer-simulated route walk-through, Golledge, Dougherty, and Bell (1995) found females were more accurate on judging absolute distance and found that female geography students were more accurate on judging both distance and direction. A comprehensive experiment by Montello, Lovelace, Golledge, and Self (1999) examined spatial abilities of 79 Santa Barbara residents ranging in age from 19 to 76 years. Participants completed a wide variety of spatial tasks – including psychometric tests, route learning both from maps and from physically walking a route, and object location from memory (seven total test scenarios were completed). In general, males scored higher on a mental rotation psychometric test, while females scored higher when recalling spatial locations of objects. There were no significant differences between genders on map learning, though males made fewer distance estimation and direction errors on sketch maps drawn after walking a campus route.

In a more recent study, Lloyd and Bunch (2005) also examined gender differences on mental rotation and memory for spatial location tasks, particularly as they related to handedness of the participant and his/her immediate family. With regards to gender in general, males were more accurate on the rotation and memory tasks, though their reaction times were slower than females. Effect sizes for the gender variable were small to medium for reaction time and confidence and were near zero for accuracy, indicating "females and males tended to be equally accurate" (p. 39). The memory task involved mentally rotating the map feature in order to compare it to the map held in memory; however, this additional demand on memory did not produce a significant interaction effect between gender and task demand.

Gender differences with GIS use have not been established in the literature. Furthermore, the impact of gender differences on various spatial ability tasks in the context of GIS use remains undetermined. Does a gender difference exist when using a GIS? Spatial decision systems provide users with a visual medium within which to perform analytical and transformative processes. Studies on GIS use and effectiveness should examine gender and GIS use in this context.

Spatial cognition

The discussion of gender differences aside, spatial cognitive abilities appear to be an important characteristic for successful GIS interaction. Spatial cognition is difficult to define, but Mark (1993) explains it as referring to a wide range of mental processes, including thought, reasoning, memory, and perception. Hart and Moore (1973) define spatial cognition as "the knowledge and internal or cognitive representation of the structure, entities, and relations of space; in other words, the internalized reflection and reconstruction of space in thought" (p. 248). Thus, the concept includes both conscious (interaction) and unconscious (storage) aspects. On a more general level, spatial cognition involves interpreting and internalizing spatial information and evaluating that information for and during problem solving.

Even though GIS were established, in the 1960s, in an effort to bring computation to map information processing (Goodchild, 2000), Rieger (1996) points out that "cognitive research in GIS is late in coming," mainly because of "the emphasis on the technical aspects in the early years of the technology" (p.18). Nevertheless, spatial ability informs one's actions and aptitudes within spatial environments and is, thus, considered an important component in GIS use (Albert, 1997; Lloyd & Bunch, 2003; Mark, Freksa, Hirtle, Lloyd, & Tversky, 1999; Rieger, 1996). In his seminal work, McGee (1979) defined two dimensions of spatial ability: spatial visualization and spatial orientation and relations. Other scholars, however, separate spatial relations into a third, separate dimension (Albert & Golledge, 1999; Gilmartin & Patton, 1984; Golledge et al., 1995). Before defining these abilities and discussing their association to GIS use, though, knowledge of geographic information space must first be elucidated.

Knowledge of geographic space can be divided into three general divisions: declarative, procedural, and configurational (Mark, 1993). Using studies of humans' cognitive maps of their environments led Golledge (1991) to posit that these divisions are stages from which general spatial knowledge develops. In terms of geographic space, declarative knowledge refers to geographical facts (Mark, 1993), such as knowledge of individual locations (Golledge, 1991). This fact-based knowledge does not include metric and orientation relationships. An example would be to know that Austin is Texas' state capital or that Atlanta is the largest city in Georgia.

Procedural knowledge, however, involves the paths that link locations. Most people develop this knowledge quite easily and accurately (Golledge, 1991). Configurational knowledge pertains to the "bird's-eye view" of geographic space, including approximations of relational location, distance between points, overall route distance, and Euclidean distance (i.e., straight line distance) (Mark, 1993). Declarative and procedural knowledge are more commonly discussed as "route" knowledge, while configurational knowledge is more commonly discussed as "survey" knowledge. Configurational knowledge develops to much more varying degrees within people (Golledge, 1991) and can, itself, exist in stages. The lowest form might be merely to mentally represent objects in their general location, along with their connections (Mark 1993); this topological representation is seen by some as an intermediate phase between procedural and configurational stages (Kuipers, 1978). The importance of survey knowledge within the context of GIS use is of ongoing interest (Golledge, 1991; Nyerges, 1993). Survey knowledge is an environmental spatial ability that pertains to spatial information management for geographical locations that cannot be seen in their entirety from one vantage point. How important is this ability when problem solving with a GIS? More importantly, perhaps, can learning and problem-solving with a GIS further develop the user's ability to interact with geographic space?

Lee (2005) notes that "there are few real-world problems that one can solve with a single GIS procedure" (p. 103); thus, his study took an integrated approach to examining spatial ability as it relates to GIS learning (i.e., using the system to perform course assignments). He developed a spatial skills test utilizing multiple-choice questions and performance exercises to test the relationship. He found strong correlations between spatial ability (as measured by his spatial test) and performance in a GIS course (as measured by grades on exams and projects). This partially supports Vincent (2004), who found a significant relationship between spatial ability and success on a GIS course project. Lee (2005) also found that GIS learning helped students improve spatial ability to solve problems (e.g., site location) and to identify patterns and correlations between sets of maps (through hierarchical ranking and chunking). However, he found no performance differences based upon gender or academic major.

Spatial visualization: Geographic spatial knowledge is operationalized through a number of spatial abilities, such as spatial visualization, orientation, and relations. Spatial visualization involves the ability to mentally manipulate, rotate, move, and transform two- and three-dimensional spatial objects and features (Albert & Golledge, 1999; Gilmartin & Patton, 1984; McGee, 1979). It encompasses movement of the parts within a spatial configuration or the rotation of an object wherein the features remain static (Albert & Golledge, 1999). The ability is often measured psychometrically with the Guilford-Zimmerman Spatial Visualization test (Albert & Golledge, 1999), the Hidden Patterns test (G. L. Allen, Miller, & Power, in press; Montello et al., 1999), and the Vandenberg Mental Rotations test (Montello et al., 1999). The ability to mentally rotate and manipulate spatial objects indicates an "ability to test complex relationships (logical, mathematical, or statistical)" and may be important in GIS functions that involve moving and combining map layers for analysis and for display (Albert & Golledge, 1999, p. 146). Higher ability could "facilitate reflexive abstraction," which may impact performing logical operations on spatial elements, a function used widely in analysis procedures using a GIS (Albert & Golledge, 1999).

Work by Velez, Silver, and Tremaine (2005) supports this supposition that higher spatial visualization ability is related to abstraction. The researchers asked participants to create three-dimensional mental images from two-dimensional representations and to perform various tasks, such as providing a count of the number of surfaces on the object and recognizing the three-dimensional object's correct orientation from four (two dimensional) options. Velez et al. found that higher spatially-skilled participants could "create accurate mental images of objects that are significantly more complex than those of participants with lower spatial skills" and that these individuals were "also better at comprehending projections with a higher number of 'hidden' surfaces" (Velez et al., 2005, p. 517). Albert and Golledge (1999) found that the number of polygon sides significantly affected the ability to mentally perform logical operations (and, or, not, xor) on two shapes; however, they did not test participants on their spatial abilities, so that relationship is unclear.

Spatial orientation: As the term implies, spatial orientation involves the ability to imagine how a visual stimulus or configuration looks from a different perspective, which requires the ability to re-orient oneself relative to a visual array (Albert & Golledge, 1999). Specifically, it

> includes the comprehension of the arrangement of elements within a visual stimulus pattern, the aptitude to remain unconfused by the changing orientations in which a spatial configuration may be presented, and an ability to determine spatial orientation with respect to one's body. (McGee, 1979, p. 909)

In short, then, spatial orientation involves the comprehension of arrangement of elements within a visual stimulus pattern (Lee, 2005) and the ability to retain those patterns as the orientation changes (Gilmartin & Patton, 1984).

Spatial orientation is often studied in reference to navigational knowledge and ability, which, as noted previously, is comprised of declarative, procedural (route) and configurational (survey) forms. Spatial orientation, however, generally is examined in the context of route knowledge and survey knowledge. Spatial orientation has been demonstrated to play a role in spatial tasks such as acquiring route knowledge during actual navigation and acquiring survey knowledge under simulation (Albert, 1997); it also informs map reading comprehension (Gilmartin & Patton, 1984). Spatial orientation appears to be indicative of the ability to develop configurational knowledge (Hirtle & Hudson, 1991), which, the reader may recall, refers to the ability to recall an overview of a geographic space and to be able to judge distances between landmarks (Mark, 1993). Spatial orientation is often measured with the Guilford-Zimmerman Test of Spatial Orientation (Albert & Golledge, 1999) "which requires users to determine the change in position implied by two views form the prow of a boat" (Hegarty & Waller 2005, p. 128). Albert and Golledge (1999) argue spatial orientation may impact GIS use, as users will have to change perspective when dealing with three-dimensional representations, such as digital elevation models, before they can make inferences about the data (e.g., shape, orientation, pattern, etc.).

Spatial relations: Spatial relations involves analyzing "patterns, shape, layout, hierarchy, and linkage between individual stimuli within a visual configuration" where mental rotation is not involved (Albert & Golledge, 1999). Specifically, Golledge et al. (1995) define spatial relations as pertaining to

> the ability to estimate or reproduce distances, angles, linkages and connectivities; to develop spatial hierarchies in which nearest-neighbor effects are prominent; to remember sequence and order as in cues along a route; to segment or chunk routes into appropriately sized units that facilitate memorization and recall; to associate distributions or patterns in space; and to classify and cluster information into meaningful spatial units such as regions. (p. 136)

Spatial relations is closely aligned with aspects of survey (Golledge et al., 1995) and configurational (Mark, 1993) knowledge, and it has been correlated with higher spatial ability (Dillemuth, 2005; Hirtle & Hudson, 1991; Montello et al., 1999), as the skill can be extended to encompass the ability to integrate spatial information across spaces, hierarchies, and geographic scales (Lloyd & Bunch, 2003). While Lee (2005) points out that contention remains as to whether spatial relations represents an actual dimension apart from spatial visualization, the majority of the literature reviewed here supports the concept. Though seldom examined in psychometric tests, spatial relations may be important in GIS functions of identifying and categorizing features, recognizing spatial association, and recognizing patterns (Albert & Golledge, 1999). Though spatial visualization, spatial orientation, and spatial relations certainly are not the only spatial abilities that could influence a user's interaction with a GIS, understanding their influence in that context would be a good start at designing effective learning experiences and user interfaces.

Map Reading Aptitude

Though a GIS provides for graphical representations, data interaction occurs primarily through the map interface; thus, map interaction also is an important component of

GIS use (Lloyd & Bunch, 2003). Maps are important for visualizing the data, for analyzing the data, and for presenting the data. While map reading skills might not be considered a spatial "ability," they certainly fall under the domain of spatial cognition, which, the reader may recall, involves interactions of perception, memory, thinking, and reasoning (Mark, 1993). A user's ability to interact with the mapped information he/she reads is another important variable. Information acquisition from maps, including the ability to recreate maps from memory (also referred to as "cognitive mapping," which is discussed in detail in the next section) and to create sketch maps of learned routes, has been an instrumental method in studying spatial cognition (e.g., G. L. Allen et al., in press; Barkowsky & Freksa, 1997; Blaut & Stea, 1971; Evans & Pezdek, 1980; and Thorndyke & Stasz, 1980). Only recently have such studies been extended to examine interaction with GIS. For the purposes of distilling relevant human factors in GIS use, a map can be defined generally as a graphical representation of spatial data and information (though the reader is directed to MacEachren, 1995, for a detailed discussion of map functions). Scholars generally accept the hypothesis that map-reading "can be described as a form of human information processing" (M. Wood, 1993, p. 114) necessary for both mental representation and in the spatial data handling process (Kraak, 2004).

Lloyd and Bunch (2003) believe map reading is a key skill when using a GIS and, thus, it deserves scholarly attention in that context. According to them, map reading involves three levels of mental involvement. The first level is visual – the whole map is created instantly in the reader's mind. The second level follows immediately and consists of schematic processes, such as categorizing, partitioning or otherwise chunking information. The second level of mental involvement engages the third level – that of moving the visual information into memory. From these mental actions, it can be extrapolated that the mental and cognitive models humans construct of the spatial information they encounter will affect how they interact with that stored information. Thus, educators, designers, and users need to understand how differences in map reading functions influences GIS interaction.

Human Spatial Information Processing

How individuals perceive (acquire), integrate (process and represent in memory), and utilize (retrieve and transform) spatial information also impacts their use of a GIS. While direct implications towards GIS interaction are only recently becoming more prevalent in the literature (but for examples, see Barkowsky & Freksa, 1997; Lee, 2005; and Lloyd & Bunch, 2003), cognitive mapping itself has a strong research stream (see Mark et al., 1999, for a review). Tolman (1948) first used the term "cognitive map" to reference how human cognition internalizes, into an organized representation, the features of physical space. However, cognitive mapping extends to structuring and internalizing any spatial information, including that acquired from maps (Lloyd, 2005) or, for example, from computer interface interaction (Zhu & Hsinchun, 2005).

Abundant research indicates both ways humans mentally model space and the systematic biases that occur in the process. In order to internalize spatial models, humans reorganize the information "first through hierarchical organization or categorization, second through the use of perspective, and third, [sic] through the use of landmarks or cognitive reference points" (Tversky, 1992, p. 131). However, just as with the loss of information and distortion that occurs through the mathematical transformation of a three-dimensional space (e.g., the world) onto a two-dimensional planar one (e.g., a paper map), so, too, must humans decide how to mentally map spatial information. Unlike the mathematical projection formula, which allows true size, shape, and position to be recovered from transformed data, the human "projection" process is permanent (Tversky, 1992). Thus, distortions become part of the mental representation and affect future processing with the cognitive map. Little is known, though, about the relationship between specific spatial abilities and cognitive map formation or which abilities make the most important contribution to cognitive map learning (Kitchen & Blades, 2002).

Hierarchical organization and categorization: One method for internalizing perceptions involves chunking the information into manageable, meaningful, units. Category theory is a framework describing the cognitive process of internalizing information, including spatial information (Anooshian & Siegel, 1985). People categorize the world in order to organize it and make sense of it. In turn, this stored knowledge informs their understanding of the world (Mennis, Peuquet, & Quian, 2000). Barbara Rosch's significant research in mental categorization, particularly from 1973 to 1978, emphasizes the constructivist nature of categorization (MacEachren, 1995; Mennis et al., 2000). In the mind, categories "are a function of properties of the elements within the environment, but as *interpreted* [italics added] by the perceiver" (Mennis et al., 2000, p. 503). Thus, while a category represents grouped concepts or features "that are somehow considered similar, or are treated in a similar way" (p. 503), biases in the individual's perceptions and existing mental models prevent rigid and uniform categorization as denoted by classical category theory (MacEachren, 1995).

Rosch's (1978) study further posits that categories are arranged in hierarchies (cited in Mennis et al., 2000). The hierarchies can be conceptualized as a graph-theoretic tree in which categories are positioned from general to specific in a top-down conceptualization. Obviously, this hierarchical reasoning also plays a role in cognitive mapping. Stevens and Coupe (1978) were one of the first researchers to provide evidence of hierarchical spatial reasoning and to show how it can distort memory of spatial relations. From memory, participants drew a line within a circular boundary to represent the orientation of one city as compared to another. A systematic error in location occurred wherein individuals believed Reno was east of San Diego. Stevens and Coupe posit the errors occur because people first mentally store relative locations of states and then store the cities within the states (as opposed to storing the relative location of each city).

Another method humans use to categorize spatial information is to separate it into chunks, layers, and scales; the method by which this operation occurs is often referred to as "partitioning" (Golledge, 1995; Lloyd & Bunch, 2003; Tversky, 1992). Chunking in the spatial context is the same as it is in other memory contexts: Humans "chunk" information bits together based upon some arbitrary factor in order to extend their short-term memory capacity, which Miller's (1956) classic work establishes at being seven bits, plus or minus two. A chunk of information is recognized and manipulated in memory as a single unit.

Partitioning occurs during information acquisition, and Lloyd and Bunch (2003) believe working memory to be "important for organizing map information before it is represented in long-term memory" (p. 832); thus, impediments, such as complex features or additional increases in cognitive load, will distort people's cognitive maps. Using a simulated GIS, Lloyd and Bunch conducted a study to examine spatial cognition, map interaction, and GIS. In addition to creating a neural-network that could successfully model learner success, the study examined user-GIS interaction effectiveness based upon behavioral variables of reaction time, accuracy, and confidence. The spatial learning task focused on the participant's ability to integrate geographic information across spaces, scales, and hierarchies, as noted by the conditions titled "chunk," "scale," "layer," and "whole." "Chunk" allowed users to view one section of the base map. "Scale" allowed the users to "zoom" in or out to three views, each of which contained different information related to the base map (e.g., cities appeared as points when zoomed out but had boundaries and shape when zoomed in). "Layer" allowed the users to view the map as layers of data; for example, a "roads" view or a "cities" view. Finally, the "whole" condition allowed users to view the base map in its entirety, but with no interactive capabilities. This was the control function for the experiment, as it did not require participants to hold past views in memory in order to integrate the material with a current view.

From the study, Lloyd and Bunch (2003) found GIS partitioning can cause interference that may lead to errors; for example, partitioning information by scale or region can impede the chunking of all like features into a cohesive unit. The researchers found that adults and adolescents having to switch between layers or regions of a map did not do as well with accuracy and efficiency as those using whole views of map data. Thus, the whole map view, where information was presented at one scale and made visible at the same time, created the most effective learning environment. The researchers theorize this approach also more closely conforms to traditional modes of teaching and learning. However, effective GIS use for spatial problem solving requires the ability to manipulate data in various formations. Educators and trainers need to understand not only how individuals' spatial chunking methods and abilities influences GIS use, but also how to extend these abilities to further GIS use.

Perspective: The scale of the respective space is another factor influencing the way humans encode spatial information. Geographic or large-scale spaces are generally considered to be greater than can be observed from one vantage point; knowledge is acquired by integrating one's experiences using memory and reasoning or by learning from maps, which represent the large-scale spaces in a manageable form (Downs & Stea, 1977). Examples could include people's comprehension of relationships between states or location cities within states, or even their understanding of a university or apartment complex layout. Small-scale or "table-top" spaces are generally "small enough to be seen from a single point, [sic] and typically are populated with manipulative objects, many of which are made by humans" (Mark et al., 1999). When dealing with maps, large-scale space refers to representation of a larger area which, by necessity, allows less physical detail to be provided than when observing a small-scale map. In contrast, small-scale maps represent a smaller geographical area but provide more physical detail. In a GIS context, scale involves zooming in/out with some attributes/features turned on /off (Lee, 2005; Lloyd & Bunch, 2003; Vincent, 2004; M. Wood, 1993). Some researchers indicate there is some question as to differences in human interaction with both forms of scaling in a GIS and in real life (i.e., Lloyd & Bunch, 2003; M. Wood, 1993).

Cognitive mapping: Spatial biases affect the representation of spatial information in memory, which, in turn, affects a person's use of that information. The mental processes involved in cognitive mapping can be viewed as a form of problem solving (Lee, 2005): People must decide what information to encode, "how [to] symbolize it, how [to] arrange and order it, and how [to] attach relative value or importance to it" (Downs & Stea, 1977, p. 77). Thus, cognitive maps can be studied through a process-oriented approach (as in spatial problem solving). This approach allows researchers to study how mental maps are constructed (Anooshian & Siegel, 1985), which is important because Lee (2005) has shown that finished sketch maps can look quite similar, even though the process to construct them was very different. That process – of beginning with general landmarks, like major roads, or beginning with quadrants, for example – speaks of the individual's encoding approach (Lee, 2005).

Spatial errors occur regarding the encoding and subsequent referencing of locations dependent upon their classification as a landmark. When landmarks are used as reference points, other entities are judged closer to them, as opposed to when relating the distance of the landmark to the reference point (McNamara & Diwadkar, 1997). Sadalla, Burroughs, and Staplin (1980) and McNamara and Diwadkar (1997) illustrated this bias using campus building landmarks (e.g., the student union and campus libraries) and ordinary buildings. Both studies found that whether people considered objects to be landmarks or not affected the perceived distance between a general object and those landmarks. Tversky (1992) notes, however, that in practice, it is difficult to distinguish whether the behavior is due to bias in the mental representation or to error in recall and processing. Little is known about the impact cognitive mapping processes have on effective GIS use. We need to understand how those processes interplay with spatial relations and orientations abilities in the context of GIS interaction.

Mental Models and Problem Solving

Turk (1990) suggests that a mental-modeling approach is appropriate in studying human computer interaction and GIS because the modeling process "mirrors GIS analysis procedures themselves" (p. 45); the process requires information acquisition, representation, and analysis. However, there are two facets to the interaction – knowledge of the system tools and knowledge of the problem context. Nyerges (1993) stresses that there is a difference between "performance in the problem domain and performance in the tool domain" and that "problem expertise is different from computer tool expertise" (p. 38). All too often, studies lump users into categories of novice or expert, which do not reflect these different components of the GIS user. Thus, Nyerges calls for a deeper understanding of both individual characteristics and of the user's work environment.

The cognitive load associated with GIS use is greater than that accompanying the use of digital or paper maps alone (Turk, 1993) and, combined with the cognitive load imposed by geographic information (Bunch & Lloyd, 2006), can be expected to affect modeling of spatially-referenced information. For one, GIS typically provide much more information than is presented by digital or paper maps. For another, the user is presented with a plethora of analysis features. However, Turk argues human and GIS interaction can be a joint action when the system presents information "in the most suitable manner and order," as this facilitates shared cognitive responsibility (p. 21). Thus, the full range of human cognition – of the problem space and of the required computer interactions – must be considered in system design through careful task analysis procedures (Turk 1993), which could then enhance mental models developed through GIS interaction.

Mental model theory is about how people draw inferences. It is a cognitive information processing structure (Ramaprasad, 1987), which makes it a problem-solving theory/model. While cognitive mapping is a form of mental modeling, cognitive maps and mental models are not synonymous. Tversky (1993) differentiates the two thusly: Cognitive maps, as internalized perceptions of an environment, maintain some semblance of metric relationship. Spatial mental models, however, allow inferencing and judgment without necessarily encoding metric perspective.

B. L. Allen (1996) states that past experiences determine how people interact with a new problem context and how they acquire information. Like Allen, Ramaprasad (1987) posits that perception is always based upon a previous mental model or cognitive map. Furthermore, he argues that a person's preferences for obtaining and interacting with information – whether directly or indirectly – will affect how the models are constructed. Research by Turk (1993), Tversky (1993), and Rauh, Knauff, Cuss, Schlieder, and Strube (2005) echoes Ramaprasad's and suggests that, when individuals encounter new experiences, prior existence of a related mental model may allow mere modification of that model, as opposed to new model development. While visual memory and recall are important in GIS interaction, being able to recall a map is not the same thing as being able to solve complex problems that require "simultaneous retrieval and integration of several map elements" (Thorndyke & Stasz, 1980, p. 145). In this regard, then, GIS interaction, with its modeling capabilities, could help to create an individual's mental model of a spatially-referenced problem context. It is here, perhaps, that GIS might have its greatest impact for increasing spatial.

Computer Aptitude and Computer Self-Efficacy

While design concerns are beyond the scope of this study, GIS interface complexity is a noted issue (Barkowsky & Freksa, 1997; Nyerges, 1993; Schimiguel, Melo, Baranauskas, & Medeiro, 2005; Scott & Schwartz, 2007; Traynor & Williams, 1995; Turk, 1993) which is mediated by an individual's computer aptitude and self-efficacy and which adds to the cognitive load of GIS interaction. Frank (1993) notes several impediments to the use of GIS, three of which are particularly relevant to this study: training, ease of use, and the GIS interface. With regards to training, Frank points out that company-sponsored employee training is costly – both fiscally and in unproductive time while learning the system. In addition, though not noted by Frank, successful training requires accommodation of the individual's learning style and, in the case of training related to and/or using technology, the individual's computer aptitude and attitude. As noted previously, however, research on GIS interaction is lacking in both of these areas. Regarding ease of use, many a GIS function is not used because "the user never finds out about it; does not understand that it could be helpful in a particular task; does know about it and wants to use it, but cannot find out how it works; [or] does know about the functionality in principle, but it seems too complicated to use" (Frank, 1993, p. 12).

Finally, the GIS interface, as the site of user interaction with the system, determines the usability of the system (Schimiguel et al.,

2005) and, thus, should be strongly correlated to an individual's computer abilities. Like Mason and Mitroff (1973), Frank (1993) notes the importance of the interface in successful system interactions and calls for formal means of assessing usability. The interface must encompass the user's conceptual requirements in order to facilitate efficient problem solving, and these requirements should be considered during the design process, not after a system has been implemented.

Computer attitude and ability are correlated to GIS use, and the inherent complexity of a GIS is one variable in that relationship (Lee, 2005). However, general knowledge of computer concepts and applications would provide a conceptual framework from which to approach the GIS interface. Furthermore, De Lisa and Cammarano (1996) and Sacuzzo, Craig, Johnson, and Larson (1996) note that many computer applications, not just software dealing with spatial data, require spatial abilities; a logical assumption is that higher computer abilities will correlate positively with various spatial abilities. Relatively few studies have considered the impact of computer attitude and ability on GIS interaction, but Vincent (2004) did examine the impact of GIS use on computer attitude and ability in an introductory college GIS course. He found that computer abilities improved but attitudes towards computers decreased. Students voiced frustration with the interface and indicated they felt the software required computer skills they did not possess. However, Vincent did not examine the relationship between efficacy and satisfaction/success within the course.

In their study, Lloyd and Bunch (2003) simulated GIS functions using a computer, but they did not examine the relationship of computer ability or attitude to the task. And, while Albert and Golledge (1999) performed some of the first research examining the effects of spatial relations on GIS tasks, they intentionally did *not* look at how computer interaction would affect the task. However, software use is a component of human – GIS interaction, and its effects need to be considered, as well. As GIS use becomes more ubiquitous in industry, education, and the community, research in computer aptitude and attitude will most likely increase.

Need for cognition

As noted previously, general cognitive characteristics such as NFC have not been studied prevalently as to their affects on a user's interaction with a GIS. Cohen, Stotland, and Wolfe (1955) describe NFC as a need to structure one's environment; Crossland, Herschel, Perkins, and Scudder (2000) define it as a measure "of an individual's internal motivation to pursue and enjoy thinking activities" (p. 17). Crossland et al. (2000) conducted an experiment wherein users performed a site-selection task using only paper maps and tabular data or also utilizing the paper-based resources along with a GIS displaying map results of commonly used data manipulations. The reader should note that participants did *not* perform the manipulations themselves; they merely reviewed the outputs to aid their decision making. Participants who measured as having a higher NFC took significantly longer on the task *and* had significantly more (three times more) errors, both with and without GIS use. The researchers posit participants with a higher NFC approached the task with such "thoughtful consideration" that they ended up "making the task more difficult than it actually [was]" (p. 21). However, inexperience with the domain also could have caused individuals with high NFC to over analyze the task. Crossland et al.'s (2000) study was the only one located that examined NFC, and it only examined the construct in context of the site selection task. Furthermore, as the study did not require actual GIS data manipulation procedures, it failed to examine NFC effects on the system use itself, where the construct might have affected, for example, tool selection or query construction.

3. DISCUSSION AND RESEARCH OPPORTUNITIES

While ample research and empirical studies exist on spatial cognition, and though, as this examination of the literature indicates, scholars recognize that the construct informs effective GIS use, there is a lack of studies examining spatial ability and cognition in the context of GIS interaction. Often, studies address spatial cognition through map reading and map sketching tasks. These studies need to be extended to the GIS context, to see how an individual's propensity to create a cognitive map affects his or her interaction with GIS analysis functions, where maps are both tools in the analytic (problem-solving) context *and* presentation media for communicating information.

GIS are becoming more prevalent in industry and in every day life (Pick, 2004), and as they become more ubiquitous, designers, educators, and researchers will need to understand the complicated interaction between the qualitative human mind and the software. More than likely, such research will seek guidance from studies such as Thorndyke and Stasz's (1980), where verbal protocol was used to capture individual processes in acquiring knowledge from maps. In addition, researchers need to borrow from the decision sciences literature in order to address affects of domain knowledge on GIS tasks. For example, studies investigating the interactive effects of domain-specific knowledge and spatial abilities, such as that conducted by G. L. Allen et al. (in press) examining information acquisition from weather maps, need to be extended to encompass a user's actual GIS interaction with such data.

Medyckyj-Scott and Blades (1992) explain that GIS software forces the user to think of space in terms of nodes, arcs, polygons, or rectilinear grids – the native formats for vector and raster data representations. However, they note that representations of space that may not correspond with the user's conceptualization of space. The researchers believe the consequence of this disconnect in spatial representation is that users will only learn to interact with a small number of operations, which will ultimately limit people's ability to exploit the GIS in its full functionality. Perhaps, though, individuals will adapt their representations. Or, perhaps it is the software, not the representations, which hinder full tool use in a GIS. Dillemuth (2005) found participants recalled more information and followed routes more accurately when using vector-based, rather than raster-based (i.e., an aerial photo), digital maps, which suggests humans may be more comfortable with vector representations than Medyckyj-Scott and Blades (1992) believe. Studies such as Dillemuth's (2005) need to be extended to a GIS problem-solving context, to see how well GIS representations interact with user's cognitive mapping procedures.

In the search to understand the user's interaction with a GIS, researchers need to understand more than spatial cognition. As Crossland et al.'s (2000) study showed, NFC also impacts accurate and efficient decision making using a GIS. In addition, measures of cognitive styles and of spatial cognitive abilities need to be correlated to each other and to GIS use. For example, for years, information systems research has examined, consistently and with relative consistency, cognitive style implications in information systems development and use. In particular, researchers often study the effects of cognitive styles such as field dependency/independency and an individual's location on the perception (feeling) and judging (logic) continuum. Such research needs to be extended to GIS contexts, as well.

In addition to benefits to industry, if GIS use does tend to increase analytic functions, as Vincent's (2004) study indicates it might, and if it does increase an individual's spatial abilities, as Lee's (2005) study indicates it does, such psychometric correlations could help to explain how and where the enhancements occur. Understanding such effects of GIS use could inform educational practices, training protocol, and system design, both by drawing on existing research on the relevant cognitive variables and by extending the existing GIS design research to include the effects of those variables. Given the interest and potential importance of GIS as educational tools, we consider it desirable to continue this line of research to determine how educators might best respond to these human factor differences.

Research in human factors of GIS use also needs to consider the problem context. Classroom scenarios are different from field experiments, which are different from real-life applications. User interaction with GIS needs to be qualitatively examined in all of these scenarios. In addition, more research needs to focus on the newly emerging GIS end-users, individuals who

- use their computers as tools to perform domain-specific tasks,
- have little (or no) programming experience,
- are not especially interested in computing technology per se, and

- are not experts in geography (Traynor & Williams, 1995, p. 142).

Research assessing the affects of domain knowledge on GIS interaction could be particularly useful here, as would a better understanding of how the general population utilizes GIS to create and understand information; such research could inform both design and training strategies.

4. CONCLUSION

At this point, however, there is a lack of user studies exploring a user's interaction processes with GIS as tools, rather than as presentation mediums. Granted, this probably is due largely to the specific nature of GIS and the difficulty in generalizing user-study findings. However, the technology is becoming more transparent, and industries are demanding systems that can be utilized with minimal or no GIS experience. In addition, participatory GIS – citizen's use of GIS in order to access public information and participate in municipal issues – is gaining ground as a viable method of citizen accessibility (Hansen & Prosperi, 2005; J. Wood, 2005). And, as GIS becomes more mobile and begin to be delivered via the Web, alleviating the financial burden of purchasing full-blown software, the general public will begin to utilize the technology for everyday information applications. Internet mapping is a prime example – it used by businesses and consumers, alike (Pick, 2004). Design issues will become more critical to facilitate inexperienced users; this includes understanding how cognitive and learning style affects a user's interaction with GIS. As well, spatial literacy education will become increasingly more important – not only for GIS interaction, but also for the impact it has on other activities that people might not consider as being spatially oriented, like computer use.

To that end, in this study we selectively reviewed extant literature examining spatial cognition and GIS use. Several key factors distinguished themselves: spatial cognition, including the abilities of visualization, orientation, and relations; cognitive mapping, including well-documented human biases in encoding and processing spatial locations; mental modeling, including the effects of context and prior knowledge; computer attitude and self-efficacy, including the use of the specific software and the impact of overall computer confidence; and individual personality traits and learning preferences, including effects of NFC, but which also could include decision style, locus of control, and other such cognitive factors. The research potential for HCI with GIS remains relatively un-chartered territory. What human factors are particularly relevant to creating information with a GIS? What influence does GIS interaction have upon a user's cognitive and spatial abilities? If we, as educators, can distill key factors, perhaps we can construct more effective learning opportunities for GIS users, programmers, and system designers. Understanding the human component with the GIS system is key to effective development and implementation. It is our hope that this brief review generates questions and stimulates readers to advance this research stream with contributions of their own.

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