Multimedia presentations that combine verbal and visual information are increasingly becoming important methods for communicating geographic information. This article discusses literature related to cognitive load theory (CLT) and offers ideas on how this theory might be used for geography education and research. By considering the limitations of the human mind, CLT offers geographers a way to assess critical components of the spatial learning processes. Methods for measuring cognitive load and reducing overloads are discussed within a map context. It is argued that managing the cognitive load experienced by learners is the key to representing geographic information. **Key Words: cognitive load theory, geographic education, maps, multimedia.**

This article presents a review of recent research on cognitive load theory (CLT) and offers ideas on how CLT can be used to complement research that involves maps, map learning, and the representation of geographic information. Particular importance is placed on the implications of CLT and its potential to contribute to research and educational practices that use maps as primary sources of information. Given the general goals of improving the presentation, representation, and learning of geographic information, many geographers should find theoretically-based research on CLT useful and practical.

Researchers and educators involved in geography have long studied ways to improve the communication and learning of geographic information. Many of these efforts have placed emphasis on the design of maps and understanding how users comprehend maps. A portion of this research has also focused on the broader goals of improving map learning and geographic education. Despite a less-than-complete understanding of how users read maps, technology has moved forward and provided a dynamic way for displaying interactive and animated maps through the Internet and other digital media. These multimedia presentations offer new ways to provide spatial information and interesting learning experiences to a wide range of people. Not all graphic displays, however, are the same (Lohse et al. 1991, 1994). Maps alone provide large amounts of spatial information representing complex associations, and the use of multimedia adds further connections that are not yet fully understood (Schwartz et al. 1998; Cartwright, Peterson, and Gartner 1999).

Professional geographers communicate geographic information to various audiences about a wide variety of topics. People receive and process this information using a number of verbal and visual cognitive systems (Verdi and Kulhavy 2002). Some geographic facts can be easily packaged as verbal information that can be acquired through reading or listening; for example, one could state that Atlanta is the largest city in Georgia as well as its capital. Geographers, however, are fond of representing spatial information on maps, and a map of Georgia’s cities may represent Atlanta with a symbol indicating both its relative size and its status as the capital. Such maps have a storage advantage in that they are able to visually and efficiently represent large amounts of equivalent verbal information. Maps also simultaneously connect specific information to spatial locations, allowing a relationship that not only enriches the map communication process, but also provides the ability to visually display broader spatial patterns.

Language processing is generally made possible by systems in the left-hemisphere of the
brain; visual and spatial information processing is facilitated by systems in the right-hemisphere (Geschwind and Galaburda 1987). The diverse possibilities for learning are addressed by geography textbooks, Web sites, and other multimedia systems that combine verbal and visual information to maximize the transfer of information. The experience of the learner, the amount and nature of the information (visual and verbal), and the combinations of cognitive systems needed to process the information all affect the learner’s cognitive load.

The term cognitive load can be thought of as the amount of work needed to acquire and use information. When the cognitive load is high for a map task, it is more likely to be difficult, take longer to complete, and impede efficient learning. When the cognitive load of a map task is low, it is more likely to be considered easy and take less time to complete, but in some instances this scenario may provide individuals with no challenge or incentive to learn.

In recent years, there has been considerable progress in the development of a theoretical understanding of how cognitive load affects people’s ability to learn (Sweller 1988; Kirschner 2002; Paas, Renkl, and Sweller 2003, 2004). Further research on CLT by geographers can greatly contribute toward this development. For geographers, CLT can offer new methodologies for understanding how map readers successfully interact and learn with multimedia maps. This understanding is extremely important as the use of computer technology for displaying spatial information becomes increasingly prevalent; especially in the areas of education and public dissemination of critical spatial information. Cartographers, as specialists, could also develop more comprehensive and robust methodologies to analyze and improve map construction and effectiveness by incorporating CLT into cartographic research. Such an approach would help theory meet practice, which has been a common obstacle plaguing cartographic research for many years (Castner 1983; MacEachren 1995). The broader implications surround a deeper understanding of how maps as graphic displays can be packaged to support geography research and educators. This understanding will lead to robust approaches for assessing the effectiveness of novel geovisualization media, and quite possibly spark new lines of research in cartography, spatial cognition, and geographic information system (GIS) interface design.

In the following section we provide background on different aspects of research in cartography. The next section is a discussion of the conceptual components of cognitive load and multimedia learning. We then consider how to reduce cognitive load, the impacts of deliberate practice in acquiring expertise, and the relevance of individual differences in learners. The final section offers suggestions for future research that should have high priority for geographers.

**Cartographic Research**

Much of early cartographic research was related to specific map design decisions that influenced the types of maps produced, as well as the symbols and structure used. The emphasis was clearly on the map and improving the transmission of intended messages (Flannery 1971; Monmonier 1974; Kimerling 1975; Olson 1975). Critics pointed out that these methods provided little theoretical understanding of the interactions taking place between the map and the map reader, and instead only determined what worked best rather than why it worked. Other researchers placed emphasis on the map user. This research has been concerned with understanding the cognitive processes associated with map users’ thought processes, prior experience, spatial abilities, and memory (Olson 1979; Gilmartin 1981; Blades and Spencer 1986). A number of more recent cognitive studies have used visual perceptual tasks to explore the effects of symbols and color on maps (Brennon and Lloyd 1993; Nelson 1995; Lloyd 1997; Bunch 1999; Bunch and Lloyd 2000) and others have emphasized the effects of prior experience, differences in spatial abilities, and memory on various map-processing tasks (Montello et al. 1999; Bunch 2000; Lloyd, Hodgsdon, and Stokes 2002; Montello 2002; Lloyd and Bunch 2003). Cognitive research on how people process maps has also received criticism. Some researchers believe that much of this research cannot translate into valid map design practices because it focuses on only one part of a complex process (Castner 1983). MacEachren (1995, 12) argues that maps should be studied as “many potential representations of phenomena in space that a user may draw upon as a source of
information or an aid to decision making and behavior in space” and that “the map user’s interaction with the map should be viewed as a complex information problem.”

MacEachren’s (1995) insight on understanding how maps work rings especially true when considering the complexities involved in using multimedia cartography. Not only do designers have to deal with the intricacies of map design itself, but the map must be wrapped as a component within a much larger spatial information interface. Multimedia, therefore, offers the ability to create a different map, one that “really extends the technology and allows for a different way of presenting geographic information to change geographical information access” (Cartwright and Peterson 1999, 4). This difference has led to arguments that the word “map,” within the context of multimedia, should be referred to as an “interactive map display” (Petterson 1999). Cartographers clearly recognize these differences and have acknowledged the need for methods and theories that consider not only the map but all other media (Crampton 1999; Dransch 1999). Difficulties in dealing with multimedia maps and geographic information are amplified in earlier work on designing, implementing, and assessing animated maps and multimedia resources for geography (DiBiase 1994; Krygier et al. 1997). We believe that CLT, along with previous cartographic and cognitive research, can contribute to the development of a much-needed theoretical foundation in multimedia cartography.

Cognitive Load Theory

By considering the limitations of the human mind, CLT offers designers, such as cartographers, a way of assessing and affecting some critical components of the learning process. CLT assumes that learners have limited working memory, which is connected to unlimited long-term memory (Baddeley 1986). Cartographers have intuitively understood that designers of maps need to consider the working-memory capacity of map users. The conventional wisdom of cartographers, for example, is to represent information on the typical choropleth map as classes. Five shades of red might be used to represent levels of population density, with the lightest shade representing the lowest class and the darkest shade representing the highest class. For a map of the United States, this would represent states that have similar population density using the same shade of red. Although it would be possible to represent each of the fifty states with a unique shade of red and this would produce a technically more accurate map, some researchers have argued that unclassed maps are too visually complex (Dobson 1979; Muller 1979).

Causal and Assessment Factors

Paas and van Merrienboer (1993) have suggested causal and assessment factors that are related to cognitive load (Figure 1). Some causal factors are expressed through the individual differences of learners, such as between females and males (Hardwick et al. 2000). More precise individual differences in spatial abilities have been explained by theories related to brain organization (Annett 1985, 2002), prior knowledge resulting from domain experiences (Schwartz et al. 1998), and their interaction (Casey 1996). Causal factors are also related to the nature of the task. Identifying which city on a country’s map is the capital city could be relatively easy, whereas determining if cities on a country’s map follow the rank-size rule could be relatively difficult (Zipf 1941). Other causal factors relate to the environment. The environment in a typical multimedia presentation might include a static, interactive, or animated map to be viewed, written text to be read, and spoken audio information or music to be heard. In many instances, there are interactions between the map task and learners that contribute to the cognitive load.

Figure 1 The causal and assessment factors of cognitive load. Based on Paas and van Merrienboer (1993).
Assessment factors, which include mental load, mental effort, and performance, are the three measurable dimensions of cognitive load. Mental load is exclusively related to the demands of the task and environment (e.g., finding a city on the map). Mental effort is the actual cognitive capacity allocated to the given task. This might include controlled processes used to learn novel information, or automated processes used to access prior knowledge. Performance is the end result that reflects mental load, mental effort, and causal factors. Being able to measure the fundamental influences on cognitive load and being able to analyze their impacts on learning success are keys to understanding how people complete basic tasks and solve specific problems (Paas and van Merriënboer 1993).

Intrinsic, Extrinsic, and Germane Components

More recent discussions of cognitive load (Paas, Renkl, and Sweller 2003; Sweller 2004) divide the load into three categories: intrinsic, extraneous, and germane. Intrinsic cognitive load is based on the demand made on working memory by the interaction of elements present in learning materials. Since working memory can handle relatively few novel interacting elements, working memory alone can support only very simple learning tasks. Long-term memory, however, can enhance this limitation by storing schemata. Although schemata can hold a large amount of information, they can also be processed as a single unit in working memory. “Schemata can integrate information elements and production rules and become automated, thus requiring less storage and controlled processing” (Kirschner 2002, 3). If a schema can be automated so it can be run unconsciously, it can further reduce the load on working memory (Paas, Renkl, and Sweller 2003).

Prior knowledge stored in schemata should be a great aid to map reading (Schwartz et al. 1998). Reference maps, for example, typically provide names for locations; for example, names of European countries may be connected to each shape. A person who has sufficiently processed such a reference map could have a schema in long-term memory that associates the names, shapes, and locations for the countries of Europe. Such an automated schema could be a great advantage when processing a novel thematic map without names, depicting population change as meaningful colors assigned to country shapes.

A second component of cognitive load—the extraneous load—can interfere with learning. The way information is presented and the activities required of learners can impose an extraneous cognitive load (Paas, Renkl, and Sweller 2003). Ambiguous task instructions (vague descriptions that require map readers to unnecessarily search for needed information) would be an example of an extraneous cognitive load. An interactive map connected to instructional information could guide attention to the needed information, causing a reduction in search time and in extraneous cognitive load.

The third type of cognitive load, germane cognitive load, can enhance learning (Paas, Renkl, and Sweller 2003). Germane cognitive load is related to working-memory resources being used for schemata acquisition and automation. The process of learning is iterative: increases in germane cognitive load develop schemata, and increases in schemata enhance germane cognitive load. The way information is presented and the activities required of learners can affect levels of germane cognitive load. An increase in effort caused by higher emotional motivation can bring fresh resources to a map-reading task and can be used to increase the germane cognitive load.

Intrinsic, extraneous, and germane cognitive loads are additive, provided they stay within the limits of the working-memory resources. Intrinsic cognitive load is constant since it relates to inherent demands of the material being learned. Extraneous and germane cognitive loads can fluctuate: an increase in one results in a decrease in the other. There is no empirical evidence or method that allows discrimination between the two. Only the total cognitive load (and how it has been affected) can be determined (Kirschner 2002).

Multimedia Learning

Mayer and Moreno (2003, 44) have proposed a theory for multimedia learning based on three assumptions about brain processes. (1) The dual-channel assumption is that “humans possess separate information processing channels for verbal and visual material.” This assumption
is based on dual-coding and working-memory theories (Paivio 1986; Baddeley 1998). (2) The limited-capacity assumption is that “there is only a limited amount of processing capacity available in the verbal and visual channels.” This assumption is based on cognitive load and working-memory theories (Sweller 1988; Baddeley 1998). (3) The active-processing assumption is that “learning requires substantial cognitive processing in the verbal and visual channels.” This assumption is based on Mayer’s (1999, 2002) selection-organizing-integrating theory of active learning. “These processes include paying attention to the presented material, mentally organizing the presented material into a coherent structure, and integrating the presented material with existing knowledge” (Mayer and Moreno 2003, 44).

We have adapted Mayer and Moreno’s theory of multimedia learning to fit the specific case of learning with maps (Figure 2). The rows of boxes in Figure 2 represent two information-processing channels: the top row is the auditory-verbal channel, the bottom row is the visual-map channel. A multimedia presentation is represented in the first column of boxes as words (top) and a cartographic map (bottom). The words represented in the sensory memory column could be processed as sensory representations by either the audio channel if spoken (top) or the visual channel if read (bottom). If a typical map, one with symbolic information as well as a title and other labels, is presented with printed explanatory text, all information is processed through the visual channel. If the same map is presented along with a spoken text, then the spoken words are processed through the audio channel and all information on the map is processed through the visual channel. The learner’s attention selects words and images for processing (first set of arrows on the left). The cartographer and multimedia designer can affect this bottom-up process by producing materials that attract the learner’s attention to important information. In addition, attention might be influenced by top-down processing of prior knowledge from long-term memory. The working-memory column represents the selected sounds and images being organized into coherent verbal descriptions of spatial information, which aids in the formation of a cognitive map. The black circle represents the merger of the verbal descriptions, the cognitive map, and any relevant prior knowledge accessed from long-term memory. A viewer’s ability to integrate these elements would impact his or her relative success at acquiring information from a multimedia presentation (Mayer and Moreno 2003).

Reduction of Overload

Mayer and Moreno (2003) identified five overload scenarios that can be related to learning with maps and offered solutions to typical problems. The first overload scenario occurs if on-screen text and a map are presented together such that the visual channel is overloaded with essential processing. Learning in this instance is improved if the text is removed and replaced by equivalent spoken information. Related studies on navigational guidance systems use a similar technique by off-loading spatial information from the visual channel to the audio channel (Streeter, Vitello, and Wonsiewicz 1985; Streeter and Vitello 1986). This technique reduces the visual competition of driving while using a map, and improves the performance of drivers who are required to navigate intricate routes.
The second overload scenario occurs if spoken text, on-screen text, or a map overloads both channels with essential processing demands. Two solutions to this problem are offered. The first involves presenting the text and information on the map in small successive segments. For example, geographic information could be presented by themes, similar to the conceptual organization of geospatial datasets in geographic information systems. Themes, such as points representing cities and lines representing roads, could be presented separately and later integrated—once sufficient learning has taken place. The second solution involves learning the roads and cities prior to performing the map-reading task.

The third overload scenario occurs if extraneous text or mapped information is overloading the verbal or visual channel, or both. Examples of extraneous information may be the inclusion of names and linear features for rivers that are unnecessary, given that the task involves learning route distances among cities. Two solutions are offered: (1) identify the extraneous information and remove it; for example, simplify the text and the map without removing necessary information; (2) direct the learner’s attention to the critical information by, for example representing critical information in the text using bold or italic lettering. This solution could be extended if rolling a mouse directs attention to critical locations on the map by pointing to them or changing their color.

The fourth overload scenario occurs if learners are confused by the way essential material is presented. Confusion may occur in the visual channel if a map is poorly designed or has visual clutter. In this case, ambiguous representations on the map should be corrected. In the verbal channel, confusion might occur if on-line text and spoken text are simultaneously presenting information. Deleting the text and relying only on the spoken word could remove redundant information.

The fifth overload scenario occurs if learners are required to hold essential text describing characteristics of countries in memory while looking at a map, or vice versa. Individual learners may vary in their ability to hold information in working memory. Well-designed instructional material may work successfully with students possessing higher spatial ability, but may not be successful with students having lower spatial ability. This critical distinction is crucial to variation in performance for a map-reading task. A solution to this type of problem would be to reduce the need to hold information in working memory by presenting the text together with the map. This may require a reduction of map size, and may also require the map to be simplified. This could also be accomplished by integrating map text with pop-up windows that appear as rollover connections to map locations.

**Gaining Expertise**

Managing the cognitive load experienced by learners is a key to successful map learning. Given that total cognitive load is the sum of extraneous, intrinsic, and germane cognitive loads, and that this total cognitive load must be less than the working-memory capacity of the learner, a number of strategies can be employed to encourage learning. Many of the earlier studies on cognitive load focused on eliminating extraneous cognitive load. Cartographers can accomplish this by making maps that focus the map-reader's attention only on the information to be learned, excluding any information that the learner does not absolutely need to process. This is a simple proposition if the cartographer knows who will be using the map as a source of information. When maps were produced only on a paper medium, cartographers were forced to design the map for a “typical” map reader. Depending on the assumptions made about the nature of this typical map reader, such an approach might not have served either a novice or advanced learner very well.

Novices may require maps that are as simple as possible in order to manage cognitive load; but, as expertise increases, a simple map may not allow learning to continue for advanced learners. This problem has been called the expertise reversal effect. It has been demonstrated in a number of studies (Kalyuga, Chandler, and Sweller 1998, 2001; Kalyuga et al. 2003), and the idea is expressed in Figure 3. The same data could be used to construct a simple map for the novice learner or a complex version of the map appropriate for the expert learner. For any given learner, the intrinsic cognitive loads provided by various map designs are also a consideration. A complex map design generally provides a higher cognitive load than does a simple map design. Designs that reduce unnecessary map complex-
ity and have lower intrinsic cognitive loads are ideal, even for advanced learners, as simplicity allows for a higher proportion of the total cognitive load as long as the map design imposes germane cognitive load.

**Measuring Cognitive Load**

If designers of maps and multimedia presentations are to consider the effects of cognitive load on learners, they have to be able to quantify the load. Paas, Renkl, and Sweller (2003) offered a method for measuring cognitive load using the computation and visualization of $z$-scores from subjective and objective measurements. Subjective measurements are gathered through the mental effort required for a task, typically measured by asking participants to rate the difficulty of a task. The objective measurement represents the performance of participants as they deal with a secondary task that is unrelated and runs concurrent with a primary task. If students are presented with a primary task of learning, for example, the population sizes of European cities from a map displayed on the computer screen, a secondary task could be introduced where they are asked to click a button whenever they detect a change in the color of a letter located on the computer screen (e.g., the letter A changing from black to red). The responses would show reaction times, and thus an objective measure related to how quickly learners are able to engage and disengage between secondary and primary tasks. The effect of cognitive load has also been simply measured as the error rate for secondary tasks (Paas, Renkl, and Sweller 2003).

Collected measurements for the mental effort and performance are standardized to produce a set of $z$-scores for each learner (Burt and Barber 1996). These individual $z$-scores for each group (mental effort and performance) are averaged to produce sample means that are plotted on a Cartesian graph against a diagonal line, where mental effort and performance are in balance (Paas, Tuovinen, et al. 2003, 68; Figure 4). Any pair of $z$-score means for a task falling into the second quadrant (top left) is considered high efficiency; a pair of $z$-score means for a task falling into the fourth quadrant (bottom right) is considered low efficiency (Brunken, Plass, and Leutner 2003). This methodology could be used while designing maps to determine if specific maps are associated with high or low cognitive loads. In this case, dark and light locations would represent two possible designs for the map (Figure 4), allowing the cartographer to determine the appropriate map for an intended audience. This information is also useful in experimental task design, or when interpreting how subjects respond to various experimental conditions. The dark and light locations, for example, could represent novice and expert learners working with the same map. Tuovinen and Paas (2004) have also shown that efficiency can be represented in a three-dimensional space, where the third dimension could be a different measurement of performance, such as reaction time or mental effort while learning the task as opposed to doing the task.
Individual Differences

The success of any educational experience involving learning with a map also needs to take into consideration the innate differences among the individuals doing the learning. A map reader’s ability to execute those cognitive processes needed to acquire information from a map may depend on factors external to the immediate educational experience. Researchers have argued that spatial abilities are a function of both biological and environmental factors (Halpern 1992; Vlachos, Andreou, and Andreou 2003; Weiss et al. 2003). Biological arguments have generally been centered on brain structure and hormones; environmental arguments have usually been related to social factors.

A number of studies have identified the biological sex of learners as a significant variable in spatial abilities. Sex can be easily coded as an independent variable for any learning study, but the actual causes of individual differences may be more complex. Research on the relationship of spatial abilities to sex typically use standardized tests that relate to a person’s ability to process spatial information (Shafer and Thomas 1998; Stumpf 1998; Dunn and Eliot 1999). Most of these tests focus on the ability to process spatial information in working memory. Other tests have considered ability to recall spatial information from long-term memory (Silverman and Eals 1992; Barnfield 1999; Silverman et al. 2000). Although psychometric tests of spatial ability have generally reported sex-related differences favoring males (Maccoby and Jacklin 1974; Harris 1981; Dunn and Eliot 1999), it has also been argued that the sexes have aptitudes for specific types of spatial tasks. Males appear to have an advantage for tasks that involve processing visual images in working memory (Linn and Petersen 1985; Halpern and Crothers 1997; Jordan et al. 2002), such as tasks involving the rotation of mental images (Masters and Sanders 1993; Voyer, Voyer, and Bryden 1995). In contrast, females appear to have an advantage for tasks requiring the acquisition of spatial information from long-term memory (Galea and Kimura 1993; Birenbaum, Kelly, and Levi-Keren 1994; Choi and Silverman 2003), such as recalling objects located in a spatial array (Eals and Silverman 1994; James and Kimura 1997).

Loring-Meier and Halpern (1999) examined sex differences related to specific tasks that required subjects to process images in working memory. Results of the study indicate that males are significantly faster but not more accurate than females when performing tasks related to visual image generation, maintenance, scanning, and transformation. Being able to process information quickly is an advantage on many standardized spatial skills tests that present more questions than most subjects are able to answer in a fixed amount of time. With this type of test, being able to process questions quickly in working memory without sacrificing accuracy can be a significant factor in achieving a high score. Since females did not appear to be able to enhance accuracy by using more processing time, the male advantage on this type of test might be explained by males’ faster processing of visual imagery. Stumpf (1998) suggested that females are in the habit of using more time to respond to spatial tasks, and that the perceived difficulty of the task and the level of self-confidence might explain differences, rather than the actual time spent processing the information. Higher self-confidence and opportunities have generally been suggested as social influences that explain male advantages in spatial processing. Females have been reported to produce higher self-confidence ratings for specific nonspatial tasks (Clifton and Gill 1994; Lee et al. 1999). Some researchers have suggested that a difference in self-confidence is more related to identifying with a gender than biological sex (Kempf, Palan, and Laczniak 1997; Johnson and McCoy 2000).

How brains are organized has also been considered as an explanation of individual differences. Sweller (2004, 9) argues that “Instructional design issues and human cognitive architecture are inseparably intertwined.” A major example of this connection for cartographers is the effect of the limited capacity of humans’ working memory on their ability to acquire information from maps. This connection has been a central and frequently researched theme in the CLT literature (Kirschner 2002; Paas, Renkl, and Sweller 2003, 2004). Another potentially key human architecture issue that could significantly influence a specific person’s performance on a map-reading task is innate spatial ability. Annett’s (1985, 2002) Right Shift Theory offers a genetic explanation of asymmetric brain organization that can be connected to human speech, handedness, and
differences in spatial ability between human females and males. She hypothesized a gene for brain lateralization that controls the probability that a person will be left-hemisphere dominant for speech, and right-handed. By this theory, those who are more right shifted for handedness tend to have better-than-average verbal abilities and tend to prefer using verbal strategies for problem solving; but they also tend to have worse-than-average spatial abilities. The theory predicts that people who are right-handed and have non-right-handed immediate relatives will have a higher probability of possessing enhanced spatial abilities. This puts them nearer the center of the population distribution for handedness because they inherited the right shift gene (RS$^+$) from one, but not both parents. They are said to have the heterozygotic advantage in spatial abilities associated with the RS$^+$ genotype.

Casey (1996) developed a Bent Twig Theory partially based on Annett’s Right Shift Theory. Casey’s theory predicts that individuals with the most enhanced spatial abilities should be those who have inherited a higher probability of having superior spatial abilities, and have improved these abilities through frequent spatial experiences. Data gathered from female students who had the heterozygotic advantage (were right handed and had immediate family members who were not right handed), and had a math/science college major, supported the prediction that they would perform better on a spatial rotation task than other female subjects without these characteristics. An individual difference variable based on family handedness and academic experience can easily be encoded for any map reader with a few simple questions. As surrogate measures for spatial abilities, this information can be used to explain performance measures for map-reading tasks. A significant interaction effect is predicted between brain organization and experience so that people with occupations requiring spatial processing (e.g., professional geographers), who also have a heterozygotic advantage, are predicted to have the best performances.

**Discussion and Future Research**

This review of the CLT literature offers possibilities for researchers and educators in geography who wish to merge theoretical research and practical solutions. CLT is concerned with providing guidelines for optimizing learner performance during the presentation of information. The cognitive architecture consists of a limited working memory, which interacts with an unlimited long-term memory, and receives information from visual and auditory processing units. As outlined in this review, recent research has identified cognitive load as a major consideration in instructional design for a number of educational areas (Yeung, Jin, and Sweller 1997). This work has clearly emphasized solving applied educational problems through the development of cognitive theory.

CLT and its applications can be adapted to design a variety of novel studies for understanding how humans process and learn geographic information. Cartographers could use CLT to understand the effects of specific map design decisions, such as the effectiveness of unclassed and classed maps. These decisions could be examined by a study that measures the effects of increasing the number of classes on a choropleth map for audiences of different skill levels. Studies of this nature could produce a set of efficiency measurements that differentiate the cognitive load of each map by different skill levels. It would also be possible to identify factors associated with cognitive load, make map design decisions to adjust the cognitive load for each factor, and compute and visualize the results. This type of research could make an important contribution to cartographic and CLT literature by considering the relative importance of effects related to the map design process and the interaction of biological and environmental differences for individuals as they learn with maps of varying cognitive loads.

Geography educators could also benefit from research based on CLT. The map has been the fundamental and traditional source for learning geographic information in the classroom. The use of maps can be very constructive in classrooms because maps can communicate information that is often too complex to easily express in words. Maps, however, can also impede learning if too much information is presented, such that the cognitive load capacity of the learners is exceeded (Mayer and Moreno 2003). The identification of instructional methods designed to accommodate cognitive load capacities of diverse learners could help
improve learning of geographic information (van Merrienboer, Kirschner, and Kester 2003). As an example, lesson plans centered on map use and reading tasks could be created from results generated by theoretically-based experimental studies that examine the cognitive load of materials prior to presentation to students. Such a study could produce instructional methods and efficiency measurements for presenting geographic information that can ultimately be assessed in the classroom through traditional performance tests. The cycle of experimentation and classroom assessment could continue until desired results are achieved. Such an approach brings forth the value of theoretical research to practitioners involved in geography education, and it also provides much needed flexibility for addressing different learning styles.

The use of multimedia technology and multimedia cartography has become popular for presenting geographic concepts and ideas. Thus far, research on the effectiveness of multimedia presentation has largely ignored geographic information and has instead placed heavy emphasis on understanding pictorial representations accompanied by words (Mayer and Moreno 2002). This leaves ample opportunity for geography researchers to explore the use of multimedia techniques that use maps as the central focus of learning (Cartwright, Peterson, and Gartner 1999).

The ability to understand and communicate geographic information is fundamental to the discipline of geography. CLT has great potential for providing an overarching theoretical context for understanding how geographic information is represented and learned. Experimentally-based research grounded in theory that fully explores these issues from an integrative view should have a prominent place on the agendas of researchers in geography.

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RICK L. BUNCH is an Assistant Professor in the Department of Geography at the University of North Carolina Greensboro, Greensboro, NC 27402. E-mail: rlbunch@uncg.edu. His research interests include GIS, cartography, and spatial cognition.

ROBERT EARL LLOYD is Distinguished Professor Emeritus in the Department of Geography at the University of South Carolina, Columbia, SC 29208. E-mail: bllloyd@sc.edu. His research interests include spatial cognition, cartography, and quantitative methods.