



CHAPTER 12

INSTRUCTIONAL GEOGRAPHIC INFORMATION SCIENCE

A Multi-Disciplinary Framework for Geospatial Technologies in Education

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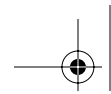
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Interest in the employment of geospatial technology as an instructional tool in K–12 social studies classrooms and other educational areas has been increasing over the past decade. A major focus has been the use of Geographic Information Systems (GIS), Global Positioning Systems (GPS), and

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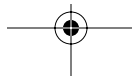
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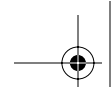




related geospatial technology to convey basic geographic concepts to students in elementary, middle, and secondary education (Audet & Abegg, 1996; Bednarz & Audet, 1999; Broda & Baxter, 2003). Classroom instruction that uses this technological potpourri to teach basic geographic concepts can be aptly called *Instructional Geographic Information Systems (InGIS)*. The impetus for *InGIS* is partially rooted in the dramatic improvements and reduction of costs in technology and the introduction of educational GIS software purchase programs. Many of these programs have provided an economical and feasible platform for purchasing and incorporating GIS into K–12 classrooms throughout the United States. In the spring of 2005, the United States Department of Labor outlined a host of current and future employment opportunities in geography, with the caveat that there will be a shortage of individuals qualified to fill the needs in many geospatial technical areas (Crosby, 2005). Moreover, geospatial technology has been recently recognized as “one of the three most important and evolving fields, along with nanotechnology and biotechnology” (Gewin, 2004, pg. 376). These advances and the development of new applications for existing technology continue to increase the demand for individuals who are trained to use geospatial technology for interpreting and evaluating the world’s complex spatial phenomena.

Unfortunately, successful exploitation of geospatial technology for instruction at all grade levels has been mixed and a number of substantial problems have emerged. Many teachers, for example, struggle with the complexities of learning the software or find it difficult to identify the role of GIS in the curriculum (Lloyd, 2001; Milson, DeChano, Bunch, Caito, & Qui, 2005). Teachers may also spend an enormous amount of time finding the best instructional strategies to support the use of GIS only to discontinue their development out of frustration (Kerski, 2003; Lloyd, 2001). Students who do receive lessons with geospatial technology are, in many cases, preoccupied with learning the software and the concept itself often gets lost in confusion (Audet & Paris, 1997; Cunningham, 2005; Kerski, 2003; Meyer, Butterick, Olkin, & Zack, 1999). Perhaps more importantly, there is very little agreement among educators, as well as researchers, about what age or grade level is appropriate for introducing geospatial technology, and whether the technology actually improves the learning experience (Audet & Paris, 1997; Battersby, Gollidge, & Marsh, 2006; Bunch, 2000; Cunningham, 2005; Gatrell, 2004; Lloyd & Bunch, 2003). A number of solutions, ranging from pre- and in-service training for teachers to various strategies for instruction, lesson plan development, and easier-to-use GIS interfaces have been offered, but many have provided inconsistent if not poor results (Audet & Abegg, 1996; Baker & White, 2003; Blaser, Sester, & Egenhofer, 2000; Gatrell, 2004; Milson et al., 2005).





Training the trainer, instructional strategies, and lesson plan development only address part of a much bigger problem. Many instructional approaches have used geospatial technology as a stand-alone educational tool with little emphasis on the extremely important underlying geographic concepts (Gatrell, 2004). Geospatial technology is used to analyze and understand the spatial relationships among phenomena distributed on the Earth's surface. One must be able to think spatially, grasp geographic concepts, and understand the world from a spatial perspective (Bednarz & Bednarz, this volume). Effective instructional use of geospatial technology should, therefore, focus on concept instruction and learning while incorporating an understanding of how spatial information are mentally learned, processed, and retrieved by students of varying ages and spatial abilities (Albert & Golledge, 1999). This approach requires the application of theories derived from collaborative experimental studies and classroom assessments that integrate views from three relevant and major disciplines—geography, psychology, and education.

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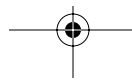
The purpose of this chapter is to provide a framework for understanding the use of geospatial technology as an instructional tool in elementary, middle, and secondary education. We take an integrative view by using cognitive and educational theories for examining how geospatial technology can be effectively used as a learning tool. We narrow the extremely large body of research from geography, psychology, and education to reflect how people think spatially within the context of maps, graphics, and other geographic displays. Our approach is intended to add the science to *InGIS* as well as shed light on the much broader and deeper issues associated with the use of geospatial technology for instruction.

The following sections provide an overview of literature related to geographic education, spatial cognition, and educational psychology within the context of developing what we refer to as *Instructional Geographic Information Science (InGIScience)*. Each section will discuss research related to using geospatial technology, maps, and graphics, for spatial learning and thinking.

INSTRUCTIONAL GEOGRAPHIC INFORMATION SCIENCE

Geography, psychology, and education are three well-established disciplines that offer much in the way of deepening our understanding of effective instructional use of geospatial technology. Each of these disciplines can be overlapped to form equally important and cross disciplinary areas of research (Figure 12.1).

Educational psychology, for example, results from the overlap of common research interests in education and psychology, and seeks to blend a



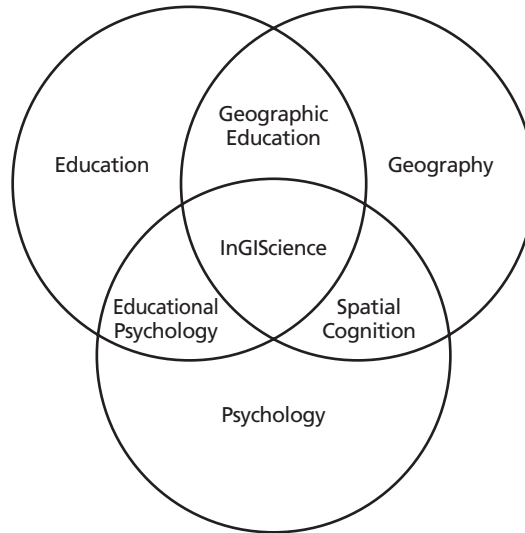


Figure 12.1. Instructional Geographic Information Science.

number of psychological and educational theories to help understand how people learn in an educational setting. Spatial cognition is the overlap of common interests between geographers and psychologists, and relies heavily on theories in geography and psychology to understand how people process, store and retrieve spatial information. Finally, geographic education—the research overlap binding geographers and educators, focuses on methodologies for improving teaching the many aspects of geography by emphasizing spatial relationships, concepts, and knowledge in an educational setting. Our proposed area of study called, *InGIScience*, is intended to provide a much richer approach by incorporating research from all three major disciplines. *InGIScience* can be further brought into focus by using research conducted in geographic education, spatial cognition, and educational psychology, all of which are intrinsically linked to three major disciplines.

Geographic Education

Geographers focus on the analysis of questions and problems from a spatial perspective, or geographic point of view. John D. Nystuen, a pioneer in spatial analysis and modern mathematical geography, defined the key concepts associated with the spatial perspective: *directional orientation*, *distance*, and *connectiveness* (1968). Similarly, Golledge & Stimson (1997), proposed three dimensions of spatial thinking: spatial visualization, spatial



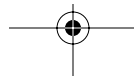


orientation, and spatial relations. The incorporation of these geographic axioms within a person's knowledge base gives them an advantage in their ability to reason in a world that is becoming increasingly connected and complex.

During the 1980s, the *Geography Education National Implementation Project* (GENIP) was established to assess the breadth and depth to which geography and its concepts were being translated to students through the nation's educational system. The National Geographic Society assembled allegiances with many other organizations to further develop a national network of interest in geography education. A poll conducted in 1988 found that Americans were far below acceptable levels in terms of geographic literacy.

Although geography is listed as a core subject within the *No Child Left Behind Act* (NCLB) of 2001, it is within the group of standards and assessments that are optional under individual state's control. In fact, geography is the only discipline without a dedicated program of provisions by the NCLB. Geography finds itself in a catch-22. NCLB measures student achievement by the use of mandatory state assessments; however, most of these assessments lack geography-related content, which mirrors the level of geography content in the classroom. Thus, the only way to be taught the material is to be tested on that material, and in order to be tested on the material, a student must be taught the material. Geography must find a way to situate itself alongside other disciplines to secure any funding. To do this, the discipline must fulfill the two top priorities for all programs: improving the academic achievement of students and providing high quality instructors. Emphasis is placed on those programs whose curricula are the product of scientifically-based research (Daley, 2003). It goes without saying that the best way to show geography's merit is to illustrate its unique and necessary role in the education of our children and to demonstrate students' effective learning of spatial skills through rigorous empirical research.

The incorporation of geographical thinking abilities into the curricula of secondary education has made modest advances over the past two decades, but there is still much work to be done if the richness of spatial analytical techniques is to help today's youth make the informed decisions needed for future success in our global society. The standards serve as educational and intellectual goals for which students should strive to achieve. Specifically, the eighteen geography standards are grouped into six foundational elements, the first of which is the ability to understand the world in spatial terms. People use maps, photographs, and satellite images to investigate the relationships between people, places, and environments. These tools display information within a spatial context. There are three geography standards that are derived from the use of these tools: (Stan-





Standard 1) How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective; (Standard 2) How to use mental maps to organize information about people, places, and environments in a spatial context; (Standard 3) How to analyze the spatial organization of people, places, and environments on Earth's surface (National Geography Education Standards Project, 1994).

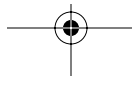
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Conspicuously underrepresented within the standards is the role of GIS in geography education. One reason for this near omission is the date of publication. In 1994, GIS was still being developed and scrutinized by the geographic community. It was initially heralded as a tool able to be utilized for the rapid and repeatable analysis inherent in geographical studies (National Geography Education Standards Project, 1994). Recently, it has gained recognition as an entity deserving consideration of becoming a major focus for its own discipline (Johnson, 2004). Although geographic analysis has been incorporated into the curricula of some American schools, more attention should be devoted to developing pedagogical approaches for this type of analysis and to examining the role for GIS in cultivating various forms of 'geographic thinking' among K–12 students.

GEOGRAPHIC EDUCATION AND GIS

The implementation of GIS in K–12 education has been slow due to both academic and administrative restraints. Since the inception of NCLB, teachers have been encouraged to focus classroom instruction on materials that will be tested by state standards assessments. Since geography is underrepresented on many of these tests, less time is directed to geographic concepts during classroom instruction. From an administrative perspective (excluding the initial hardware and software costs), the chief challenges most educators face in implementing GIS are a lack of training and support for the teachers, a lack of time to develop appropriate lesson plans, and the complexity of the software.

These restraints on GIS implementation and expansion are worth overcoming for several reasons. First, the incorporation of GIS may encourage students to examine data from a variety of fields. Both Jacobs (1989) and Audet & Abegg (1996) believe that an interdisciplinary approach to learning may be effective in helping students to develop problem-solving skills. The power of a GIS is that it allows us to ask questions of data. Students use an inquiry approach to form research questions, develop a methodology, gather and analyze data, and draw conclusions (National Geography Education Standards Project, 1994). Many of the models for GIS implementation in educational setting are constructivist and interdisciplinary in nature





(e.g., Alibrandi, 2003; Alibrandi & Sarnoff, 2006; Baker & White, 2003; Bednarz, 2000). This allows for emphasis to be placed on the content area rather than on the system itself. Students are enabled to learn the material being presented with little distraction from the computer interface (Kerski, 2003). Palladino (1994) posited that despite its inherent spatial reasoning incentives, GIS can be utilized to enhance various teaching methods, to provide better delivery of subject matter than textbooks alone, and to prepare students for spatial technologies in the workforce.

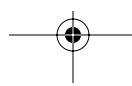
Studies of the effectiveness of GIS for enabling the learning of spatial reasoning within students have thus far been mixed. As pointed out by Bednarz (1994) and Meyer (1999), initial studies tended to focus on the ability and need for learning GIS software and not the ability of GIS to serve as a tool for enhancing students understanding of core geographic principles or axioms. Many of these studies indicate, for instance, that students develop technology skills as opposed to the spatial analytical skills sought after by the implementation of GIS. This outcome has been rationalized by many as due to the barriers of introducing GIS within the classroom—acquisition of hardware, software, and training for teachers (Meyer, 1999; Kerski, 2003). Studies by Meyer et al. (1999), for example, illustrate the potential setback that GIS computer software learning curve can place on students. Throughout the instruction period, considerable time was needed to learn the basic functions and capabilities of the software. Hence no difference in learning was recorded between groups of students utilizing GIS versus those who did not. Qualitative measures indicated that cartographic output was the only merit of the GIS incorporated lesson plans. In another study, however, Patterson, Reeve, & Page (2003) found that although test scores were lower than expected for all students, high school students receiving instruction through GIS scored significantly higher on test materials than college students without GIS-based instruction. Kerski (2003) also encountered mixed results when testing high school students. No significant differences were found when utilizing standardized and spatial analysis tests, although significant differences were found with respect to content-specific material.

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Spatial Cognition

It is within the fields of spatial cognition and educational psychology that answers may be found for incorporating GIS into K–12 education more effectively. Spatial cognition studies have the potential to inform educators about how spatial information is most effectively acquired, processed, stored, and used. Geographers and psychologists share an interest in the cognition of space; however, they focus on the topic in different





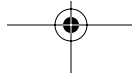
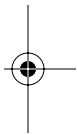
ways. Psychologists have a very broad interest in how spatial information is encoded, stored, and used (Forman & Gillette, 1997). These interests include a concern with how spatial information is acquired and represented in memory structures, how spatial abilities develop as the human brain matures, and how learning processes related to spatial cognition can be modeled (Jacobs & Schenk, 2003; Kohonen, 2001; Stiles-Davis, Kritchevsky, & Bellugi, 1988). Geographers have typically taken a narrower and more practical approach (Lloyd, 1997a). Spatial cognition studies conducted by geographers are more likely to involve real-world locations, use authentic stimuli such as maps, and give attention to practical applications.

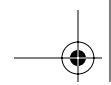
Geographers studying spatial cognition topics have adapted many of the theoretical positions and experimental methods developed by psychologists. These adaptations provide avenues for evaluating geographic instruction and for understanding how people learn and think about space, especially from maps and geographic displays which are often generated by students and teachers who employ GIS. Studies of visual attention provide an effective starting point for examining these methodological linkages (Lloyd, 2005a; Schneider & Maassen, 1998).

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Nelson (1999, 2000a, 2000b), for example, has done a series of studies that investigated how visual attention is used to understand maps and their symbols. The studies investigated how map readers obtained information from bivariate map symbols using selective attention concepts and the perceptual grouping of features. This study categorized the experimental symbols according to how the dimensions of the symbols (e.g., size and shape or hue and value) visually interact. Three types of dimensional interactions were identified with the following theoretical predictions. Map readers viewing symbols with separable dimensions should be able to attend to the two dimensions independently. Map readers cannot, however, view one integral dimension of a map symbol without processing the other integral dimension. The same map readers should be able to attend to configural dimensions of symbols independently. Configural dimensions are special, however, in that they are able to interact to produce an emergent property that takes priority over the original dimensions.

Nelson's subjects were trained to classify experimental symbols according to specific rules. When subjects applied the rules, they were required to attend to one specific dimension, selectively attend to either dimension while filtering out irrelevant dimensions, or attend to both dimensions simultaneously. Reaction times for the experimental trials were analyzed and used to design thematic maps with the aim of easing the map interpretation process in bivariate scenarios. As an example, consider a map of the spatial relationship between education and income at the county level in the United States. Symbolizing the relationship graphically with an integral symbol will enhance map reader's abilities to "see" the connections





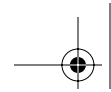
between the two datasets, while symbolizing the relationship with a symbol whose dimensions are separable will better enhance abilities to study each dataset separately.

On a related topic, additional spatial cognition studies have considered how representations of geographic space, e.g., maps and aerial photographs, are searched for information. Lloyd (1997b) constructed map symbols for his experimental map using the dimensions of color, size, shape, and orientation. Subjects sometimes searched for target map symbols that had a unique feature, compared to distracter symbols, and other times searched for target map symbols that shared features with distracter symbols. For example, a target symbol might have the unique feature red on the color dimension and other distracter symbols would have a feature other than red on the color dimension. According to cognitive search theories, target symbols with a unique feature should “pop-out” of the map, but target symbols that share features with distracter symbols should not (Duncan & Humphreys, 1992; Treisman & Gelade, 1980; Wolfe, 1994). Experimental results supported the predictions of the visual search theories, but feature differences on the color dimension produced the best “pop-out” effect, suggesting color to be one of the stronger symbol dimensions from the perspective of enhancing map interpretation.

Another visual search study that featured color as a critical variable had subjects search for color boundaries on choropleth maps (Bunch & Lloyd, 2000). Subjects were presented a pair of colors on either side of a common boundary as the target of a specific search trial. They were then presented a state map that had the counties filled with various colors that was searched to determine if the target boundary was present. Results indicated that highly luminous targets, e.g. red and yellow boundaries, were found more quickly. The similarity of the colors in the target boundary and the colors in non-target boundaries and the similarity of colors in the set of non-target boundaries also significantly affected search times.

A separate category of studies have modeled how representations of geographic space are encoded in people’s mind. These types of studies provide insight into how people learn and think about space, and offer further guidance in the development of GIS as an instructional tool. We must know, for example, how students learn and process spatial information in order to teach them about spatial concepts and relationships, especially when using GIS as an instructional tool. This understanding can provide a starting point for developing GIS-based instructional strategies that address the strengths and weaknesses of students’ spatial learning. Lloyd (1994), for example, investigated the learning of a prototype map, i.e. a representation of the most typical map, for a series of maps representing a particular category. Prototype maps were found to be significantly affected by the arranged sequence of individual example maps studied by subjects.





Prototypes learned by human subjects were also found to be similar to prototypes learned by auto-associator neural networks. The identification of the prototypical map for different age groups can lead to designs that incorporate this knowledge as a map template in GIS.

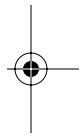
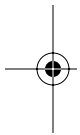
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Other studies have used Kohonen's self-organizing map (SOM) neural network models to simulate the learning of point distributions, i.e., cities in a geographic space (Kohonen, 2002; Lloyd, 2000). Lloyd (2005b) had SOM neural network models learn the locations of cities in a state that were known by human subjects from three different home locations in the state. Models that had previously learned the state boundary and Interstate highway system before learning the cities consistently produced results that more closely matched the locations of the cities on sketch maps produced by human subjects.

A few studies have considered the cognitive processes related to visually processing the spatial information being presented as a product of a geographic information system. Bunch (2000), for instance, investigated how humans integrate information related to city locations mapped in a Geographic Information System. Subjects learned the information using four different experimental procedures (chunk, layer, scale, and whole) that simulated functions employed in a GIS. These procedures required subjects to integrate the spatial information across spaces, hierarchies, and geographic scales. Results indicated that the age (young adolescent or adult) and the type of integration process used to learn the information significantly affected the cognitive map of city locations learned by the subjects. This further suggests that not only the design of the geographic product being used, but also the instructional method by which it is presented and the age of the product users, may have a significant effect on the learning of spatial information.

Lloyd & Bunch (2003) used the same maps and learning procedures as Bunch (2000), but had subjects respond to True/False statements regarding the nature of the spatial information they had learned with the aid of a GIS. The reaction time, accuracy, and confidence of subjects were predicted with a back-propagation neural network model using characteristics of the learners, experimental conditions related to GIS functions, and map features (points, lines, and areas) as inputs to the model. Subjects generally were more accurate and confident in tasks that required less integration of geographical information. Young adolescent learners were slower, less accurate, and more confident than adult learners for all experimental conditions.

Albert & Golledge (1999) used an experimental design to study the cognitive abilities of subjects responding to questions related to logical operators, i.e., AND, OR, XOR, and NOT, that might be used in a GIS. Subjects worked with three related sources of information, i.e., input





layer, output layer, or logical operator. They were given two of the three and required to select the correct corresponding third. Results indicated significant differences among the logical operators, but not differences based on the sex of the subjects or their prior experience with geographic information systems.

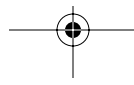
In a related study, Battersby et al. (2006) used pencil and paper tests to consider incidental learning of overlay concepts. In one study, they provided three levels of subjects (middle school, high school, and university undergraduates) with two maps (crop and soil) of the same farm and asked subjects how they would determine which areas on the farm have sandy soil and grow wheat. They were then asked to color in this area on the crop map. Since none of the subjects had any formal instruction on how to solve this problem, the study was designed to assess if subjects had incidentally learned the AND overlay process. Results indicated that university and high school subjects both used an overlay process more frequently and solved the problem more accurately. A second and related study showed the same three levels of subjects examples of AND, OR, and NOT overlay operations (Battersby et al., 2006). University and high school subjects again were generally able to solve map overlay problems better than middle school subjects. The authors concluded that the concept of map overlay is too complex to be learned incidentally by middle school students, and would therefore require instructional intervention.

Educational Psychology

It is in the educational psychology arena that we find the methodologies to evaluate the instructional methods of geographic education as paired with the design methodology and guidelines that stem from spatial cognition. Paas & colleagues (2007) offer *Cognitive Load Theory* (CLT) as a foundation for examining the linkages between instructional materials/products and our abilities to use them effectively. CLT has its basis in memory, of which two types are important: limited short-term and unlimited long-term. It is the interaction between these two types of memories that is crucial, and the interactions are influenced by both task demands and spatial abilities (Paas, Renkl, & Sweller, 2003).

which one?

From a cartographic perspective, this is not necessarily a new idea; map makers have always intuitively understood the need to consider memory capacities in the context of map design. This is, in fact, the basis for several conventional design guidelines, including the simplification of information through categorization processes. What is new is the ability, through CLT, to assess the cognitive load for various map designs and instructional scenarios and to adjust designs and instructions accordingly for groups, and perhaps,



individuals. Although not yet tested in *InGIScience*, CLT has worked well in several other disciplines, including physics, mathematics, computer programming and electrical engineering (Paas & Van Gog, 2006).

Cognitive Load

Cognitive load, according to Paas & van Meriënboer (1994), is influenced by both causal and assessment factors (Figure 12.2).

Individual differences, as well as task and environment are considered causal factors. Take task and environment, for example. The decision of where to best locate a new airport involves considering several criteria, from surrounding land use, to soil quality, to any other of a variety of components. This decision, however complicated, may become exponentially more so if levels of uncertainty must also be factored in for each criteria. Differences arising from changes in available geographic knowledge, then, can significantly affect cognitive load for a task.

Individual differences may also play a factor in manipulating cognitive load. Although gender is one important variable that has received attention (Hardwick, Bean, Alexander, & Shelley, 2000), studies investigating gender differences have produced mixed results (Engle & Kane, 2004). More precise differences in individual spatial abilities have been noted in theories related to brain organization (Annett, 1985, 2002), working memory capacity (Kane, Hambrick, Tuholski, Wilhelm, Payne, & Engle, 2004), prior knowledge resulting from domain experiences, or the interaction among several such factors (Casey, 1996).

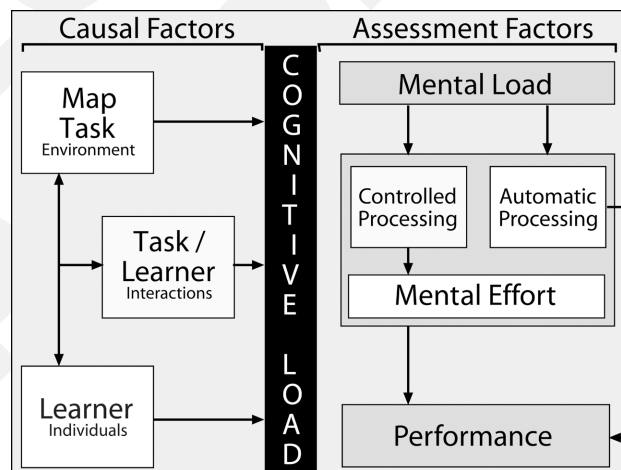


Figure 12.2. Causal and assessment factors of cognitive load (Adapted from Paas & van Meriënboer, 1994).

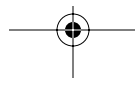


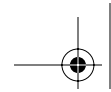
Also affecting the cognitive load associated with tasks are assessment factors. Mental load, mental effort, and performance are measurable, and form the basis for measuring cognitive load in CLT. *Mental load* is part of the total cognitive load, and reflects the demands of task and environment in the decision-making scenario. *Mental effort* is the cognitive capacity that the learner allocates to the given task, and *performance* is the end result that reflects the *mental load*, *mental effort*, and the *causal* factors combined in a subject's decision.

Components of Cognitive Load. In addition to varying factors influencing cognitive load, it is also important to realize that recent research subdivides cognitive load into three components, each unique in what it brings to the evaluation of a cognitive task (Paas et al., 2003, p. 2). *Intrinsic* cognitive load, for example, addresses the working memory demand associated with interacting with materials and instructions. It is well-known that working memory is limited and can handle only a few interacting elements (Cowan, 2001), so this is a limiting component of cognitive load. As an example, consider the difference between learning how to apply a buffer to a linear feature and learning how to interpret the interaction of that buffer with other geographic layers to make a decision about habitat suitability. Learning to apply a buffer to a river is a low-interactivity task. Learning how to interpret the river's buffer, however, can be a high-element activity if students were required to relate the results to vegetation, human development, and other geographic influences to identify the best habitat for an endangered species.


Working to offset the limitations of working memory is long-term memory (LTM). LTM helps by allowing us to store *schemata*, which are "...cognitive constructs that incorporate multiple elements of information into a single element with a specific function" (Paas et al., 2003, p. 2). Prior knowledge is stored in LTM and can be categorized by use (Chi, Glaser, & Rees, 1982). Prior knowledge may be stored as schemata and may help to reduce cognitive load as it can be referenced and retrieved as a single unit in memory (Schwartz, Ellsworth, Graham, & Knight, 1998). Knowing the names and locations of all the countries in the world, for example, would aid in learning the locations of all world major cities. Moreover, knowing that higher probabilities for human lead exposure exists in subdivisions built prior to 1978 would aid an analysis on blood-lead level risks in GIS.


Working to the detriment of overall cognitive load is the *extraneous* component of cognitive load. Extraneous cognitive load addresses the manner in which information is presented and the resulting learning activities required. Ambiguous instructions, for example, increase cognitive load by requiring users to search unnecessarily for the information needed to com-






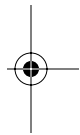
plete a task. Ambiguous classification of data on a map, poor symbology, or irrelevant data layers in a GIS are further examples.

While *extraneous* cognitive load interferes with map use, the third of the  components, *germane* cognitive load, can actually enhance learning (Paas et al., 2003). which one? Germane cognitive load can reference the user's motivation and/or the creation and use of schemata in performing tasks. A thorough knowledge of how GIS works and marketing can enhance *germane load*, and thus learning if an individual is exploring where to locate a new retail bank. These three forms of cognitive load are additive and together produce a total cognitive load that should not exceed the limits of working memory if learning is to be efficient and successful.

A Methodology for Measuring Cognitive Load. Cognitive load and its associated concepts must be measurable to make them useful in designing, implementing, and evaluating the instructional materials and GIS interfaces needed to promote the use of *InGIScience* to enhance geographic learning in education. On  method for accomplishing this is offered by Paas and colleagues (2003). which one? Their method harnesses both objective and subjective measurements that are converted to z-scores and analyzed visually and statistically. Subjective measurements are typically ratings of difficulty; objective measurements are response times of users as they deal with a secondary task that is unrelated and runs concurrently with the primary task.

If a GIS user, for example is presented with a primary task of finding the intersection of a river buffer with a certain species of vegetation, they might also be asked to concurrently detect a change in the color of a letter located on the computer screen. Responses to the color change would produce reaction times indicative of how quickly the users were able to disengage from the primary task. The longer the reaction times, the higher the cognitive load of the primary task (Posner & Boies, 1971).

Objective and subjective measurements are standardized to produce a set of z-scores for each user. These are then averaged to arrive at sample means, which can be plotted on a graph. The horizontal axis of the graph represents perceived mental effort; the vertical axis represents reaction-time performance. The diagonal is a balance between the two (Paas et al., 2003).  which one? Figure 12.3 shows, any pair of z-score means for a task falling into the second quadrant (top left) is considered representative of a highly efficient task; here, performance exceeds effort. In contrast, a pair for a task falling into fourth quadrant (bottom right) is considered representative of low efficiency; here, effort exceeds performance. High efficiency is considered to have low cognitive load while low efficiency is considered to have high cognitive load (Brunken, Plass, & Leutner, 2003).



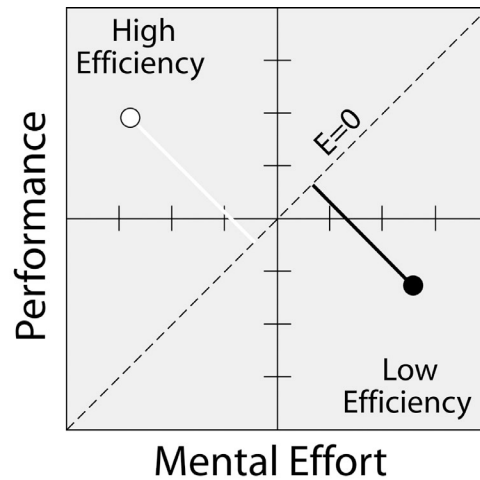


Figure 12.3. Cartesian Graphic used to visualize instructional efficiency. Group score means are plotted against the diagonal line ($E = 0$) (After Paas et al. 2003).

CONCLUSION

Geospatial technologies are dynamic tools for studying spatial relationships between and among people, places, and objects throughout the world. This dynamic quality lends itself to the types of inquiry-based learning that is at the forefront of constructivist theory in education today. The creation, production, and analysis of interactive maps enable students to hone spatial analytical skills. The advent of the Computer Age and the Internet is allowing for the almost direct contact between cultures never before having been introduced to each other, let alone engaged in daily interaction. This phenomenon has necessitated the advancement of geographic thought in our society. This advancement must first and foremost take place in the education of our youth. Existing research from geographic education, spatial cognition, and educational psychology, taken together, can provide a formal structure for using geospatial technology as an effective educational tool. The successful citizens of tomorrow's global society will be those with the greatest understanding of the spatial interconnectedness of the world's regions and its peoples.

Previous approaches to understanding *InGIS* have been narrow and fragmented, and, as a result, its effectiveness in teaching and learning are unclear (Audet and Paris, 1997; Kerski, 2003). Perhaps exacerbating this ambiguity is the complexity of GIS itself and notion that many *InGIS* endeavors have only focused on part of the complex process e.g., the focus

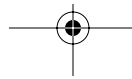


on application at the expense of the underlying geographic concepts. This view is supported by evidence from research that has argued for a need to understand the age at which geographic concepts can be learned before they are applied (Battersby et al., 2006). As outlined earlier in this chapter, a plethora of previous research has both directly and indirectly echoed this sentiment, and the need for more robust methods for examining *InGIS* is becoming increasingly evident. As a natural extension to *InGIS*, therefore, we argue for a richer, integrative, and multidisciplinary approach called *InGIScience*. As part of this approach, educational psychology and related cognitive load theories can help measure and provide context for understanding how students of various ages and abilities learn geographic information. This work can also provide an opportunity to identify deficiencies in spatial abilities that can be alleviated through practice, and thus increase the likelihood of effective *InGIS*. Moreover, these theories can be bolstered by research in spatial cognition that has examined the processes involved in using and learning from maps and geographic displays generated by geospatial technology. Together, these two areas of research can be placed within the context of research conducted in geographic education to focus on understanding the interaction between the instructor and students through the technology so that learning outcomes can be maximized.

Research threads found within geographic education, spatial cognition, and educational psychology can be woven together to achieve optimum educational goals. *InGIScience* has the potential to provide the overarching and integrative context for understanding the fabric of this collaborative environment because it focuses on multidisciplinary approaches. Experimentally based research grounded in *InGIScience* should be a high priority for those who wish to use geospatial technology as an educational tool.

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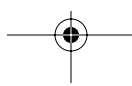
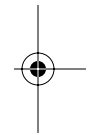
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