Behavioral and Cognitive Geography

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Introduction

Behavioral geography is an approach to human geography that attempts to understand human activity in space, place, and environment by studying it at the disaggregate level of analysis—at the level of the individual person. Behavioral geographers analyze data on the behavior of individual people, recognizing that individuals vary from each other. A key tenet of behavioral geography holds that models of human activity and interaction can be improved by incorporating more realistic assumptions about human behavior. For example, behavioral geographers agree with other human geographers that distance (or related factors such as travel time or effort) is an important determinant of human activity, but they maintain that it is subjective rather than objective distance that is typically important. It's not how far away the store is that matters, it's how far away you think it is. And because different people's beliefs about distances may vary considerably from one another and from objective distance, spatial activities will be more variable and less optimal than nonbehavioral models predict. Thus, the disaggregate study of human geography naturally leads behavioral researchers to consider what the individual knows or believes about the world as playing an important role in explaining what the individual does or will do—that is, people do what they do because of what they think is true. People evaluate decision alternatives according to their beliefs in order to make behavioral choices in space and place. What people think, in turn, arises from perceptual knowledge acquired via the senses, as organized and interpreted by existing beliefs and schematic knowledge structures and processes. These, in turn, are products of people's genetic and experiential histories and are often mediated by symbolic representations, such as maps and language. To recognize how prominent the study of human mind has become in behavioral geography, as well as in many other science and humanities disciplines, I explicitly refer to this subarea as behavioral *and* cognitive geography. Behavioral and cognitive geography further maintains that human-environment relations are dynamic and bidirectional: The actions and mental states of individuals cause, and are caused by, physical and social environments, within the context of ongoing and changing interactions. Because of these various interests and beliefs, behavioral and cognitive geography has inherent interdisciplinary connections, particularly with various subfields of psychology, but also with other behavioral and cognitive disciplines, such as linguistics, anthropology, economics, neuroscience, and artificial intelligence, and environmental disciplines, such as planning, architecture, urban studies, and environmental studies. Given this fundamental interdisciplinarity, much of the literature cited here has been published not only within geography and cartography, but also within psychology, linguistics, computer science, and other fields.

General Overviews

More than some other fields of geography, the best overviews of behavioral and cognitive geography may be found in edited books with chapters by different authors. This reflects the relative newness of the subfield, its extremely multidisciplinary nature, and its wide relevance to so many disparate problem areas within geography and cartography. At the same time, it has attracted relatively few scholars within geography (few departments specialize in it, for example). The most important and informative early edited collections include Downs and Stea 1973 and Gärling and Golledge 1993. Golledge and Stimson 1997 constitutes the most authoritative and broad general book on behavioral and cognitive geography to that point in time; it is the much-expanded second edition of an earlier version by the authors. Jakle, et al. 1985 and Denis 2018 are additional relevant authored books. Walmsley and Lewis 1993 is better suited as a textbook for introductory courses. Amedeo joined Golledge in Amedeo and Golledge 2003 to provide Golledge's final written assessment of the behavioral approach generally. Finally, Montello 2018 is the most recent authoritative general book on behavioral and cognitive geography, with great coverage breadth again, but of even greater multidisciplinarity than earlier works.

Amedeo, Douglas M., and Reginald G. Golledge. "Environmental Perception and Behavioral Geography." In *Geography in America at the Dawn of the 21st Century*. Edited by Gary L. Gaile and Cort J. Willmott, 133–148. Oxford: Oxford University Press, 2003.

Statement of the core ideas, methods, and context of the traditional historical core of the behavioral and cognitive approach as it emerged over the years, from the views of the "Environmental Perception and Behavioral Geography" specialty group of the AAG (Association of American Geographers, labeled the American Association of Geographers since 2016). Authored by two of its long-time leaders, the chapter highlights the philosophical tensions historically found within this approach between what has been labeled "positivist" and "post-positivist" perspectives on human activity and experience in space and place, basically a contrast between scientific and humanist perspectives such as phenomenology (see also Philosophy of Behavioral and Cognitive Geography).

Denis, Michel. *Space and Spatial Cognition: A Multidisciplinary Perspective*. London: Routledge, 2018.

Contemporary book authored by a leading researcher on spatial cognition from a behavioral and linguistic perspective, nicely combining perspectives from most of the disciplines involved in behavioral and cognitive geography research and technologies, even though written by a single author.

Downs, Roger M., and David Stea, eds. *Image & Environment: Cognitive Mapping and Spatial Behavior*. Chicago: Aldine, 1973.

Edited collection that is not only very important historically to behavioral and cognitive geography, but that contains several chapters that are among the most influential sources on their particular topics. Includes chapters by prominent geographers, psychologists, and others. Perhaps no other single reference in all of behavioral and cognitive geography is more important in its impact on the development of this subfield.

Gärling, Tommy, and Reginald G. Golledge, eds. *Behavior and Environment: Psychological and Geographical Approaches*. Amsterdam: North-Holland, 1993.

Edited collection of value because it consists of review chapters covering much of the breadth of behavioral and cognitive geography, written by top scholars. Uniquely contrasts the perspectives of geography and psychology on each major topic it covers.

Golledge, Reginald G., and Robert J. Stimson. *Spatial Behavior: A Geographic Perspective*. New York: Guilford, 1997.

Probably the broadest treatment of behavioral and cognitive geography by a single set of authors found in one source. Does a very good job of connecting the behavioral and cognitive approach to the general field of human geography. More appropriate for graduate courses than undergraduate.

Jakle, John A., Stanley Brunn, and Curtis C. Roseman. *Human Spatial Behavior: A Social Geography*. Prospect Heights, IL: Waveland, 1985.

An interesting early overview of scientific human geography that is essentially a balanced and broad presentation of behavioral and cognitive concepts and idea. Covers mental, behavioral, social, and cultural uses of space by individuals and groups.

Montello, Daniel R., ed. *Handbook of Behavioral and Cognitive Geography*. Cheltenham, UK: Edward Elgar, 2018.

Contemporary edited collection that reviews behavioral and cognitive geography broadly and comprehensively, with chapters by many of the leading researchers and scholars from several disciplines. Includes chapters reviewing the state-of-the-art in nearly every topical area within behavioral and cognitive geography, including sets of chapters on spatial behavior and decision making, environmental spatial cognition, cognitive aspects of geographic information, individual and group differences, and environmental attitudes. Opens with

introductory chapters extensively reviewing the approach and discussing its academic history and concludes with an entertaining chapter that considers the future of behavioral and cognitive geography.

Walmsley, D. J., and G. J. Lewis. *People and Environment: Behavioural Approaches in Human Geography*. 2d ed. New York: John Wiley, 1993.

Rare example of something like an adequate undergraduate text in behavioral and cognitive geography. Like Golledge and Stimson 1997, it provides a broad coverage that connects the behavioral and cognitive approach to the rest of human geography, but more concisely and at a more basic level.

Historical Background

Early scholarship that links geography and cartography with psychology and other behavioral and cognitive sciences may be found from as early as the turn of the twentieth century, and influential literature appears sporadically throughout that century. Particular geographic research problems within this literature have included spatial orientation and disorientation, geographic education, map design, human aspects of urban planning and landscape design, and models of spatial behavior and interaction, including travel, communication, and economic activity. An important presidential address at the annual meeting of the AAG, published in Wright 1947, was an early and widely disseminated call to geographers to study the subjective. In Tolman 1948, a prominent behaviorist psychologist argued for the need to understand behavior in rats and people in relation to mental representations of the world. This would come to greatly influence geographers and other scholars of space and place. Lynch 1960 made similar arguments for our understanding of the built environments of cities, as did Saarinen 1966 with respect to the study of human responses to natural hazards. Many of these strands coalesced during the 1960s, when behavioral and cognitive geography became recognized as a distinct approach within human geography, especially with the appearance of Cox and Golledge 1969. Other central publications in the history of the field of behavioral and cognitive geography include Hägerstrand 1970, which initiated the study of space-time geography to understand the activity of individual people; Gould and White 1974, with its emphasis on emotional responses to places; and Tuan 1974a (cited under Philosophy of Behavioral and Cognitive Geography), which helped popularize an experiential approach to understanding subjective geography. The cognitive approach to understanding reasoning and decision making by lay persons was initiated and popularized in Simon 1952, Wolpert 1964, and Tversky and Kahneman 1974.

Cox, Kevin R., and Reginald G. Golledge, eds. *Behavioral Problems in Geography: A Symposium*. Evanston, IL: Northwestern University, Department of Geography, 1969.

This edited collection can be cited as the origin of the field of behavioral geography, at least by that name. Based on a landmark meeting of scholars from several disciplines, it is the earliest overview and introduction to the field.

Gould, Peter, and Rodney White. *Mental Maps*. Harmondsworth, UK: Penguin, 1974.

This work demonstrated to geographers that emotion can be studied scientifically. Its name is potentially confusing, as the book focuses on depicting place preferences in the form of exceptionally engaging isoline maps. It is not much concerned with broader issues of place cognition implied by the term “mental map,” usually considered a synonym for cognitive map.

Hägerstrand, Torsten. “What about People in Regional Science?” *Papers in Regional Science* 24.2 (1970): 7–21.

Groundbreaking work introducing space-time budgets and time geography. Discusses various types of constraints on the locations of spatial activities, dependent on the time available to travel particular distances, as a function of one’s transportation mode, the need to collaborate with others, the need to return home at night, and so on.

Lynch, Kevin. *The Image of the City*. Cambridge, MA: MIT Press, 1960.

From an urban planner. No reference work played a more important formative role in the systematic study of the mind-environment interrelation. Important for its concepts of urban “images” (really long-term mental representations) and urban legibility. Also provided appealing visualizations of shared mental representations and introduced the method of sketch mapping.

Saarinen, Thomas F. *Perception of Drought Hazard on the Great Plains*. Chicago: University of Chicago, 1966.

Short book directing researchers to the importance of subjective beliefs in determining how people respond to potential and actual environmental hazards. Builds on earlier groundbreaking work by geographers, notably his doctoral advisor Gilbert White, who persuasively made the case that human activity plays a fundamental role in bringing about so-called “natural” hazards (see Environmental Risks and Hazards).

Simon, Herbert A. “A Behavioral Model of Rational Choice.” *Quarterly Journal of Economics* 69.1 (1952): 99–118.

Very influential and heavily cited paper in the early development of behavioral economics, the analogue to behavioral geography and one of the primary stimuli for its development. Provides a basis to model economic decision making (including in the geographic domain) with the help of a more psychologically realistic understanding of human reasoning in place of the long dominant assumption of economic rationality (“Economic Man”). Famously introduced the behavioral concepts of “satisficing” and “bounded rationality.”

Tolman, Edward C. “Cognitive Maps in Rats and Men.” *Psychological Review* 55.4 (1948): 189–208.

Influential psychological research that helped end the hegemony of the behaviorist perspective in English-language psychology. It posited that animal (including human) behavior is controlled not just by external stimuli but also by mental representations of environments, which Tolman termed *cognitive maps*. His observations of rats shortcutting in mazes is still widely taken as key evidence for what is now called survey or configurational knowledge.

Tversky, Amos, and Daniel Kahneman. “Judgment under Uncertainty: Heuristics and Biases.” *Science* 185.4157 (1974): 1124–1131.

Important paper launching widespread theory and research on the psychology of decision making by lay people in many contexts, popularizing the key role of heuristics—simple and quick rules of thumb—that often work well but also lead to systematic biases in decisions. Among the most important products of a famously fruitful research collaboration between two experimental psychologists. Theory has had major influence on the study of reasoning in several problem areas within human geography, including spatial behavior, economic decision making, and hazard perception.

Wolpert, Julian. “The Decision Process in a Spatial Context.” *Annals of the Association of American Geographers* 54.4 (1964): 537–558.

Applied behavioral work on decision making, such as that in Simon 1952 interrogating the assumption of economic rationality, to an explicitly geographic context. Wolpert tested economic rationality and found it inadequate to explain agricultural land-use decisions by a sample of Swedish farmers.

Wright, John K. “Terrae Incognitae: The Place of Imagination in Geography.” *Annals of the Association of American Geographers* 37.1 (1947): 1–15.

Perhaps the earliest call from a prominent geographer for the merits of studying the subjective geographic beliefs of lay people as well as experts, whatever their objective validity. He called this *geosophy*. Based on Wright’s 1946 presidential address at the annual meeting of the AAG.

Philosophy of Behavioral and Cognitive Geography

The twentieth and twenty-first centuries have been characterized by extensive and repeated discussions about the nature of geography as an intellectual endeavor. What is its basic problem domain? What are appropriate geographic concepts and methods? How should geography position itself as a natural science, social science, or branch of humanities or the arts? What are the social and political implications of geography and how should geographers respond to them? Collectively, these are metaphysical concerns—core questions about the philosophy of geography. Behavioral and cognitive geography has participated in its share of these philosophical discussions, if not more than its share. As Golledge 1981 discusses, behavioral and cognitive geography has typically adopted a scientific approach, which advocates the use of systematic empirical and analytic methods, including quantification where feasible, and certain other assumptions such as realism (yes, a person's beliefs can be thought of as real beliefs) that tend to distinguish it rather sharply from other approaches that also advocate the study of the subjective in human geography, i.e., the contrast between positivist and post-positivist perspectives mentioned above. (Sack 1980 presents a fascinating philosophical discussion of the study of the subjective in geography.) Critical appraisals of behavioral and cognitive geography have contrasted scientific approaches with post-positivist approaches derived from the humanities, including philosophy, history, and literature (most notably Tuan 1974a). Some critics have advocated these various post-positivist approaches to the study of the subjective and experiential (e.g., Bunting and Guelke 1979, Tuan 1974b), approaches such as humanism, phenomenology, postmodernism, critical theory, and other approaches. In its typical positivist form, behavioral and cognitive geographers have been criticized for treating humans too individualistically, overlooking the social and cultural context of human activity. Other critiques have focused on the mentalistic nature of much behavioral and cognitive geography that seemingly leaves a person frozen in daydreams or pondering over alternatives. Such mentalism sometimes confuses cognition with consciousness, lacking nuance in conceptualizing the relationship of mind and behavior (Bunting and Guelke 1979). Like work in the tradition of the quantitative revolution in general within human geography, some behavioral and cognitive work can be characterized as simplistically and somewhat mindlessly quantitative (e.g., Tuan 1974b), too theoretically empirical, and too intent on listing values of test statistics and probability levels over meaning. In part because of these critiques, behavioral and cognitive geography has lost popularity within human geography since the 1980s (Argent and Walmsley 2009), even as it has facilitated interdisciplinary connections with other unapologetically scientific fields that study the mind, such as experimental psychology and computer science (see Mark and Frank 1991, cited under Behavioral and Cognitive Aspects of Geographic Information Science). Conversely, supporters of behavioral and cognitive geography have argued for the plausibility and value of scientifically studying the subjective (see Argent and Walmsley 2009 and Golledge 1981). They have criticized some approaches to human geography for failing to appreciate rigor or for misunderstanding the claims of behavioral and cognitive geography. And they have questioned the appropriateness of scholars *qua* scholars mixing their search for understanding with a politicized advocacy of causes such as social justice.

Argent, N. M., and D. J. Walmsley. "From the Inside Looking Out and the Outside Looking in: Whatever Happened to 'Behavioural Geography'?" ***Geographical Research*** **47.2 (2009): 192–203.**

Overview of legacy and current status of behavioral and cognitive geography from a metaphysical perspective. Defends its aims and achievements while observing its decline within mainstream human geography for some decades. Notes several valuable conceptual and methodological contributions of behavioral and cognitive geography that enrich modern geography, even while much behavioral and cognitive research has moved to interdisciplinary outlets.

Bunting, Trudi E., and Leonard Guelke. "Behavioral and Perception Geography: A Critical Appraisal." ***Annals of the Association of American Geographers*** **69.3 (1979): 448–462.**

Severe and trenchant criticism of behavioral and cognitive geography. Doubts that perceptual and cognitive research is of much value in explaining actual human activity. Questions the validity with which mental states can be measured and quantified and expounds on the relatively weak and complex relationship between mind and behavior.

Golledge, Reginald G. "Misconceptions, Misinterpretations, and Misrepresentations of Behavioral Approaches in Human Geography." ***Environment and Planning A*** **13.11 (1981): 1325–1344.**

Wide-ranging defense of behavioral and cognitive approach by one of its key originators and its most productive and vocal proponent. Deals mostly with some of the early criticisms of behavioral and cognitive geography, such as its confusion with behaviorism in philosophy

and psychology (which is profoundly anti-mentalistic).

Sack, Robert David. *Conceptions of Space in Social Thought: A Geographic Perspective*. London: Macmillan, 1980.

Philosophical and conceptual overview of the study of the subjective in geography. Considers both the level of individual minds and that of collective cultural beliefs.

Tuan, Yi-Fu. *Topophilia: A Study of Environmental Perception, Attitudes, and Values*. Englewood Cliffs, NJ: Prentice-Hall, 1974a.

Following John K. Wright, David Lowenthal, and others, this is essential writing on the importance of the experiential, emotional, and contextual in geography. Squarely within the humanities tradition (particularly humanism and phenomenology), it has been widely read by scientific and humanities scholars alike. Tuan's books offer some of the best belletristic writing in geography.

Tuan, Yi-Fu. "Review of *Mental Maps* by Peter Gould and Rodney White." *Annals of the Association of American Geographers* 64.4 (1974b): 589–591.

Erudite and concise critique of scientific behavioral and cognitive geography, spurred on within the context of a critique of Gould and White 1974 (cited under Historical Background) on preference mapping. Expresses humanist doubts about the value of quantitatively measuring human experience, emotion, and meaning in space and place.

Spatial Behavior, Activity Spaces, and Time Geography

The original motivation of behavioral and cognitive geography when it emerged as a distinct approach during the 1960s was to explain human activity in space and place at the disaggregate level of the individual person. While this led some behavioral and cognitive geographers to the study of cognition, others continued to focus on measuring and analyzing individual spatial behavior and activity. These include both temporary travel, such as the journey to work, and the relatively permanent mobility involved in migrating to a new home. Hägerstrand 1970 (cited under Historical Background) presented several new and widely influential concepts to the study of spatial activity, particularly focusing geographers on the temporal aspects of activity and not just the spatial. Miller 2005 represents some of the most powerful modern work on time geography, particularly exploiting the tremendous potential of new technologies for automated geographic information collection and processing. Kwan 1999 focuses time geography on gender issues; at the same time, the author furthers a reconciliation of qualitative and quantitative approaches within human geography. Van Acker, et al. 2010 extends activity research by integrating it with social psychological theories to help explain why socio-demographic variables affect travel choices. Torrens 2012 pushes the envelope by integrating agent-based computational modeling with virtual-reality simulation in the context of complex and sophisticated modeling of human pedestrian activity in built environments.

Kwan, Mei-Po. "Gender and Individual Access to Urban Opportunities: A Study Using Space-Time Measures." *Professional Geographer* 51.2 (1999): 210–227.

Revises the concept of accessibility in light of space-time constraints, especially as experienced by women. Data from travel diaries are analyzed in a network-based geographic information system (GIS). Part of an extensive research program combining time geography, GIS, qualitative methods, and gender issues.

Miller, Harvey J. "A Measurement Theory for Time Geography." *Geographical Analysis* 37.1 (2005): 17–45.

Pushes the seminal approach to time geography in Hägerstrand 1970 (cited under Historical Background) considerably forward by proposing analytic definitions of its basic concepts, including space-time paths, prisms, and more. These definitions support rigorous and explicit comparisons of time geographic data across different contexts, especially valuable given the explosion of data and data-processing capabilities in the last several decades, set within a GIS framework.

Torrens, Paul M. "Moving Agent Pedestrians through Space and Time." *Annals of the Association of American Geographers* 102.1 (2012): 35–66.

Demonstrates the potential of advanced agent-based simulation in human geography. Attempts to show the power of implementing the disaggregate approach of behavioral and cognitive geography into a computational model. Argues that such models work better when based on more realistic formalizations of human locomotion and mind, as well as of surrounding environments.

van Acker, Veronique, Bert van Wee, and Frank Witlox. "When Transport Geography Meets Social Psychology: Toward a Conceptual Model of Travel Behaviour." *Transport Reviews* 30.2 (2010): 219–240.

Pushes the behavioral approach to transportation geography forward by integrating it with social psychological theorizing, such as the theory of planned behavior. This helps explain why socio-demographic variables influence transport activity, as is commonly reported in research on transportation.

Spatial Knowledge and Cognitive (Mental) Maps

Cognition is knowledge and knowing by sentient entities, including humans, nonhuman animals, and artificially intelligent machines. Cognitive structures and processes include those of sensation, perception, thinking, learning, memory, attention, imagination, conceptualization, language, and reasoning and problem solving. Some of these structures and processes are consciously accessible, potentially available to awareness; others are nonconscious, outside of awareness. Following the lead of Tolman 1948 (cited under Historical Background), but with even earlier precedents, behavioral and cognitive geographers and other researchers in spatial cognition have studied spatial knowledge of the environment conceptualized as *cognitive maps*. Kitchin 1994 gives a broad overview of this concept and its applicability to geographical problems. McNamara 1992 and Tversky 1992 present excellent concise overviews of work on distortions in spatial knowledge and what they suggest about the form and processing of spatial knowledge. Golledge 2002 presents an ambitious theory of "primitives" of all kinds of geographic spatial knowledge. Waller and Nadel 2013 is a recent and authoritative handbook covering work on human spatial cognition, by several leading researchers.

Golledge, Reginald G. "The Nature of Geographic Knowledge." *Annals of the Association of American Geographers* 92.1 (2002): 1–14.

Based on the author's AAG presidential address, this article presents a theory of the geographic knowledge of expert geographers and lay people. Discusses spatial thinking in geography in a broad sense, including thinking about location, distance, network, hierarchy, region, and more.

Kitchin, Robert M. "Cognitive Maps: What Are They and Why Study Them?" *Journal of Environmental Psychology* 14.1 (1994): 1–19.

Overviews the concept of cognitive maps and their relationship to a variety of basic and applied research questions in geography and other disciplines.

McNamara, Timothy P. "Spatial Representation." *Geoforum* 23.2 (1992): 139–150.

Concise review by a leading cognitive psychologist written for a geographic audience. Clearly describes most of the empirical phenomena that demonstrate properties of spatial beliefs and reasoning by lay people, as inferred from distorted judgments of distance, direction, and so on.

Tversky, Barbara. "Distortions in Cognitive Maps." *Geoforum* 23.2 (1992): 131–138.

Another concise review by a leading cognitive psychologist written for a geographic audience. A somewhat different interpretation that also clearly describes the empirical phenomena demonstrating properties of spatial beliefs and reasoning as inferred from distorted spatial judgments.

Waller, David, and Lynn Nadel, eds. *Handbook of Spatial Cognition*. Washington, DC: American Psychological Association, 2013.

Authoritative overview of spatial cognition primarily from a psychological perspective, especially focusing on the domains of perception, memory, learning, reasoning, and neuroscience. Edited collection from several leading scholars.

Distances, Directions, and Regions

Some of the research on spatial knowledge by behavioral and cognitive geographers and other behavioral and cognitive scientists has concentrated on particular elements of knowledge rather than cognitive maps in general. Tversky 1981 demonstrates how the mental processing of spatial knowledge at different scales distorts judgments of directions in certain ways. Other references deal in detail with the regional organization of spatial knowledge. Regions are spatial categories—pieces of earth surface that capture aspects of similarity among the places within the regions. *Cognitive regions* are informal region concepts individuals or groups of lay people use to organize their understanding of the earth surface (culturally shared informal regions are known as *vernacular* regions). Aitken and Prosser 1990 presents an interesting method for studying neighborhoods as cognitive regions at urban scales. Friedman and Brown 2000 was the first in a line of studies that investigated the influence of cognitive regions at continental and national scales, particularly how this regional organization influences spatial judgments such as latitude and distance. Stevens and Coupe 1978 and Hirtle and Jonides 1985 extend the study of cognitive regionalization to considering how the hierarchical arrangement of cognitive regions influences the nature of spatial reasoning. Gao, et al. 2017 demonstrates the use of data-scientific approaches based on social media "big data" to study cognitive regions and other mental concepts in lay people.

Aitken, Stuart C., and Rudy Prosser. "Residents' Spatial Knowledge of Neighborhood Continuity and Form." *Geographical Analysis* 22.4 (1990): 301–325.

Methodologically innovative empirical study of residents' beliefs about what constitutes their neighborhoods, an important example of an informal cognitive region.

Friedman, Alinda, and Norman R. Brown. "Reasoning about Geography." *Journal of Experimental Psychology: General* 129.2 (2000): 193–219.

Initiates major research program on spatial reasoning with cognitive regions at continental and national scales, based on estimated latitudes, longitudes, distances, and more. Shows spatial distortion due to regional reasoning is conceptual and not only perceptual, contra Tversky 1981. The most extensive work on "psychological plate tectonics" (p. 218).

Gao, Song, Krzysztof Janowicz, Daniel R. Montello, et al. "A Data-Synthesis-Driven Method for Detecting and Extracting Vague Cognitive Regions." *International Journal of Geographical Information Science* 31.6 (2017): 1245–1271.

Innovative use of "data science" techniques to extract cognitive regions from social media data. Compares results to the cognitive regions of "NorCal" and "SoCal" previously extracted with traditional behavioral-science human-subjects data.

Hirtle, Stephen C., and Jon Jonides. "Evidence of Hierarchies in Cognitive Maps." *Memory & Cognition* 13.3 (1985): 208–217.

Demonstrates regional and hierarchical organization of spatial knowledge on a college campus. Novel use of landmark recall protocols to determine clusters (regions) of landmarks, based in part on functional or semantic associations, not just spatial proximity or regional boundaries. In turn, these clusters influence spatial (distance) judgments about landmarks.

Stevens, Albert, and Patty Coupe. "Distortions in Judged Spatial Relations." ***Cognitive Psychology*** **10.4 (1978): 422–437.**

Describes four much-cited original studies positing hierarchical spatial reasoning as a basis for certain typical distortions in reasoning. Most famously, lay people often say San Diego is west of Reno when it is actually east, purportedly because the state of California is considered entirely west of the state of Nevada.

Tversky, Barbara. "Distortions in Memory for Maps." ***Cognitive Psychology*** **13.3 (1981): 407–433.**

Notable early empirical demonstrations of distortions in spatial recall for features at different scales, from local environments and from cartographic maps, both real and fictional. Phenomena such as alignment in recalling continents and rectilinear distortion in recalling street directions interpreted to result from simplifying heuristics in spatial learning and reasoning.

Learning Environments Directly

At the environmental scale, such as the scale of home territories (whether rural or urban), people have traditionally acquired knowledge of the spatial properties of particular places by direct sensorimotor experience traveling around them. That is, they learn from visually and proprioceptively apprehending the environment around them while standing, walking, biking, driving, sailing, and so on. This knowledge varies in its completeness, accuracy, geometric sophistication, and so on. At a minimum, it may consist of minimally spatial memory traces of the appearance of distinctive features, or "landmarks." More spatially, it may consist of linear sequences of connected features along routes, perhaps with very imprecise quantitative scaling of distances and directions. At its most sophisticated, people may acquire detailed and metrically rich understandings of the two-dimensional layout of the environment. Siegel and White 1975 presents a very influential psychological theory of the cognitive changes that occur over time as one learns a new place, such as a previously unvisited city, a process called spatial *microgenesis*. Couclelis, et al. 1987 provides a different theory of spatial microgenesis, more from the perspective of geography than psychology. Thorndyke and Hayes-Roth 1982 provides a process model of spatial learning and estimation within a large building that specifically contrasts knowledge acquired from directly experienced environments with that learned from cartographic maps. Kuipers 2000 presents the most detailed theoretical framework available for human spatial learning and cognitive-map formation from the perspective of artificial intelligence and robotics. Ishikawa and Montello 2006 empirically investigates theories of directly acquired knowledge, pitting the framework in Siegel and White 1975 against a more continuous and quantitative alternative theory. Chrastil and Warren 2013 presents a well-designed and carefully conducted experimental study of active versus passive learning of environments, one of the major questions about how different ways of learning spatial layouts affects what is learned.

Chrastil, Elizabeth R., and William H. Warren. "Active and Passive Spatial Learning in Human Navigation: Acquisition of Survey Knowledge." ***Journal of Experimental Psychology: Learning, Memory, and Cognition*** **39.5 (2013): 1520–1537.**

The question of whether active learning of environments leads to different knowledge acquisition than passive learning has long been explored, but despite what many people intuitively expect, empirical evidence is quite mixed. That is partly because the distinction has several meanings, including at least whether travelers make their own route choices or not, and whether travelers generate and control locomotion with their bodies (as when walking) or merely view optic flow resulting from movement (as in a desktop virtual reality). Among other things, the authors' results cast doubt on the full suitability of desktop virtual reality as a simulation of actual travel in real environments.

Couclelis, Helen, Reginald G. Golledge, Nathan Gale, and Waldo Tobler. "Exploring the Anchor-Point Hypothesis of Spatial Cognition." ***Journal of Environmental Psychology*** **7.2 (1987): 99–122.**

Presents an influential conceptual model of spatial microgenesis—learning the spatial properties of unfamiliar environments over time. Initially, key locations ("anchor points") such as one's home serve as points of organization around which new spatial knowledge is referenced. Separate regions acquired this way often become mutually organized over time, eventually.

Ishikawa, Toru, and Daniel R. Montello. "Spatial Knowledge Acquisition from Direct Experience in the Environment: Individual Differences in the Development of Metric Knowledge and the Integration of Separately Learned Places." ***Cognitive Psychology*** **52.2 (2006): 93–129.**

Longitudinal study of spatial learning after repeated automobile trips through a novel, complex neighborhood. The pattern of spatial knowledge acquisition fits neither the stage-like progression of the "dominant" theory (from Siegel and White 1975) nor the continuous progression of the "alternative" theory well, but instead shows strong differences among individuals according to their sense-of-direction (see also Individual, Sex, and Cultural Differences).

Kuipers, Benjamin. "The Spatial Semantic Hierarchy." ***Artificial Intelligence*** **119 (2000): 191–233.**

The most nuanced and developed computational theory of human spatial learning of environments in the context of navigation, distinguishing the separate acquisition of various types of topological and metric knowledge. By an artificial-intelligence researcher well versed in behavioral and cognitive science.

Siegel, Alexander W., and Sheldon H. White. "The Development of Spatial Representations of Large-Scale Environments." In ***Advances in Child Development and Behavior*****. Vol. 10. Edited by Hayne W. Reese, 9–55. New York: Academic Press, 1975.**

An exceptionally influential conceptual model of spatial microgenesis. Posits three stages of increasingly sophisticated spatial knowledge structures acquired over time from direct sensorimotor experience during locomotion: landmark, route, and survey or configurational knowledge. For several years, it was so widely accepted that it was dubbed the "dominant" theory (see Ishikawa and Montello 2006).

Thorndyke, Perry W., and Barbara Hayes-Roth. "Differences in Spatial Knowledge Acquired from Maps and Navigation." ***Cognitive Psychology*** **14.4 (1982): 560–589.**

Analysis and empirical confirmation of detailed conceptual models of differences in cognitive structures and processes involved in estimating directions and distances, both straight-line and route, based on spatial knowledge learned either directly from walking through a large public building or from studying a cartographic map of the building.

Neuroscience of Geographic Behavior and Cognition

Behavioral and cognitive geographers generally agree with behavioral and cognitive scientists more broadly that behavior and mind emerge from the interaction of the nervous system with the body acting in a physical and sociocultural world. The nervous system consists of the brain and spinal cord, as well as peripheral nerves throughout the body's trunk and limbs. Of increasing interest to scientists who want to explain the mind is a complex and fascinating organ—the brain. Although most behavioral and cognitive geographers would not be so reductionistic as to claim that the mind is just the expression of the brain, thereby ignoring the important roles of the body and surrounding world, they have increasingly shown interest in the scientific study of the role of the brain in the genesis and operation of the geographic mind. This *cognitive neuroscience* has made great strides in the past two to three decades, especially because of advances in brain imaging techniques and other technologies for observing the operation of the brain in living and alert humans and other animals (especially functional magnetic resonance imaging, typically referred to by its abbreviation of fMRI). Cognitive neuroscience relevant to geography has especially been stimulated by the groundbreaking work of O'Keefe and Nadel 1978 on the role of the brain's hippocampus in cognitive mapping (see Historical Background). Important examples of this work are found in Aguirre and D'Esposito 1999; Maguire, et al. 2000; and Epstein, et al. 2017. Since the start of the twenty-first century, geographers and cartographers have begun paying attention to neuroscience research (Lobben, et al. 2009). It is plausible that many of the most significant advances in understanding behavioral and cognitive geography will come from neuroscience in the next decades.

Aguirre, Geoffrey K., and Mark D'Esposito. "Topographical Disorientation: A Synthesis and Taxonomy." *Brain* 122.9 (1999): 1613–1628.

Early and still influential model elaborating the brain areas and interconnections responsible for navigation and spatial learning. Posits the localization of four component skills of environmental spatial cognition in four areas of the brain: egocentric processing of location in the posterior parietal cortex, allocentric heading in the retrosplenial cortex, landmark identification in areas of the inferior temporal cortex, and cognitive-map formation in the medial temporal lobe (in the hippocampus). Based in part on a taxonomy of disorders of orientation found in clinical patients.

Epstein, Russell A., Eva Zita Patai, Joshua B. Julian, and Hugo J. Spiers. "The Cognitive Map in Humans: Spatial Navigation and Beyond." *Nature Neuroscience* 20 (2017): 1504–1513.

Updated review of research that supports a neuroscience model for the formation and operation of cognitive maps in spatial learning and navigation. Argues for the utility of research with rats to understanding the neural basis for cognitive mapping in humans. This research places the neural instantiation of cognitive maps in so-called place, grid, border, and head-direction cells in various areas of the brain involved in spatial coding, landmark anchoring, and route planning.

Lobben, Amy, Meghan Lawrence, and Judith M. Olson. "fMRI and Human Subjects Research in Cartography." *Cartographica* 44.3 (2009): 159–169.

One of the first reviews of research focusing on the application of cognitive neuroscience to cartography and geography. Covers research using fMRI to study perceptual grouping and figure/ground discrimination in visual search and attention, recognized as relevant to understanding map use.

Maguire, Eleanor A., David G. Gadian, Ingrid S. Johnsrude, et al. "Navigation-Related Structural Change in the Hippocampi of Taxi Drivers." *Proceedings of the National Academy of Sciences of the United States of America* 97.8 (2000): 4398–4403.

Analyzes structural MRIs of the brains of London taxi drivers. This form of MRI shows anatomical brain structures instead of the metabolic function revealed by fMRI. London taxi drivers have traditionally passed an extensive test of their knowledge of streets and landmarks in the city, known colloquially as "The Knowledge." They also develop extensive experience navigating the large and complex path network of London over time. Brain scans reveal a positive correlation of posterior hippocampus volume with status as a taxi driver versus a non-taxi driver, and with additional driving experience among the taxi drivers. Research widely publicized in popular media and extensively cited in the scientific literature.

O'Keefe, John, and Lynn Nadel. *The Hippocampus as a Cognitive Map*. Oxford: Clarendon, 1978.

Extended the idea in Tolman 1948 (cited under Historical Background) of the cognitive map to research on its coding in brain structures such as the hippocampus, eventually helping to stimulate an explosion of research on the cognitive neuroscience of spatial thinking. It also led to the awarding of the 2014 Nobel Prize in Physiology or Medicine to John O'Keefe.

Navigation and Wayfinding

Navigation is coordinated movement of oneself through the environment in order to reach a destination, according to Golledge 1999. It may be conceptualized as consisting of locomotion and wayfinding (Montello 2005). Locomotion is the component of navigation coordinated to the immediate surrounds, allowing people to avoid barriers, walk toward visible beacons, and related tasks. Wayfinding is the component of navigation coordinated to distant features, out of sensory access, allowing people to plan routes, orient to nonperceptible destinations, and related tasks. Both nonconscious information processing, such as feature recognition, and conscious information processing, such as strategic thinking (discussed in Cornell, et al. 1992), play a role in navigation. In many situations, navigation is aided by cartographic maps

and other information displays, as discussed in Levine 1982 (See Spatial/Geographic Language for research focusing on verbal navigational instructions or “route directions.”) In many situations, navigation is a social activity, including the involvement of navigational tools developed over time by cultural accumulation; Hutchins 1995 presents a fascinating discussion of this aspect of navigation. Advances in understanding the neuroscience of navigation, particularly the wayfinding component, are reviewed in Ekstrom, et al. 2018, with an important critique in Taube, et al. 2013. The very different and increasingly popular data-scientific approach is applied to understanding wayfinding as route choice in Manley, et al. 2015; it demonstrates a behavioral approach to transportation geography and engineering.

Cornell, Edward H., C. Donald Heth, and Wanda L. Rowat. “Wayfinding by Children and Adults: Response to Instructions to Use Look-Back and Retrace Strategies.” *Developmental Psychology* 28.2 (1992): 328–336.

Demonstrates the effectiveness of explicitly trained strategies, particularly the look-back strategy, in helping both older children and young adults maintain orientation during a walk through a college campus. Exemplary empirical research combining empirical control with ecological realism.

Ekstrom, Arne D., Hugo J. Spiers, Véronique D. Bohbot, and R. Shayna Rosenbaum. *Human Spatial Navigation*. Princeton, NJ: Princeton University Press, 2018.

Best written and most up-to-date book available on the perception, cognition, and neuroscience of human navigation.

Golledge, Reginald G., ed. *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. Baltimore: Johns Hopkins University Press, 1999.

Authoritative chapters written by geographers, psychologists, biologists, and computer scientists. Sections cover cognitive maps and wayfinding, perceptual and cognitive processing of environmental information, wayfinding and cognitive maps in nonhumans, and the neural and computational bases of wayfinding and cognitive mapping.

Hutchins, Edwin. *Cognition in the Wild*. Cambridge, MA: MIT Press, 1995.

Novel and influential analysis of human navigation as a socially and culturally situated activity. Extensively analyzes both the nontechnological marine navigation system of traditional Micronesian navigators and the technologically aided marine navigation on US Navy ships.

Levine, Marvin. “You-Are-Here Maps: Psychological Considerations.” *Environment and Behavior* 14.2 (1982): 221–237.

Aligned you-are-here maps depict the forward-facing direction of map viewers as up on the map; other map orientations are misaligned. Empirical studies explore the *alignment effect*, the robust phenomenon in which some combination of extra time, error, or subjective difficulty in wayfinding usually occurs when people interpret misaligned you-are-here maps.

Manley, E. J., J. D. Addison, and T. Cheng. “Shortest Path or Anchor-Based Route Choice: A Large-Scale Empirical Analysis of Minicab Routing in London.” *Journal of Transport Geography* 43 (2015): 123–139.

Good example of a data-scientific approach to behavioral and cognitive geography (see Gao, et al. 2017, cited under Distances, Directions, and Regions). Presents research on human navigation behavior that analyzes about 700,000 minicab routes across London to model route choice by cab drivers, showing they clearly do not choose routes in most cases just to minimize distance. Example of the behavioral approach within transportation geography and engineering.

Montello, Daniel R. “Navigation.” In *The Cambridge Handbook of Visuospatial Thinking*. Edited by Priti Shah and Akira Miyake, 257–294. Cambridge, UK: Cambridge University Press, 2005.

Overviews behavioral and cognitive terms and concepts of human navigation as an everyday activity of lay people. Distinguishes wayfinding and locomotion as key components of navigation, whether technologically aided or not. Goes over the processes of orientation and disorientation in navigation. Considers the roles of maps and the layout of physical environments.

Taube, Jeffrey S., Stephane Valerio, and Ryan M. Yoder. "Is Navigation in Virtual Reality with fMRI Really Navigation?" *Journal of Cognitive Neuroscience* 25.7 (2013): 1008–1019.

Important critique of the nearly universal use of desktop virtual reality (VR) to study the cognitive neuroscience of human navigation (as in works cited under Neuroscience of Geographic Behavior and Cognition). The major concern of these authors is the lack of actual body movement as research participants lie in a supine position while viewing a monitor during simulated locomotion.

Behavioral and Cognitive Aspects of Geographic Information Science

Geographic information science (GIScience) is the interdisciplinary study of research issues surrounding geographic information and the computational systems for storing, processing, analyzing, and displaying it. Behavioral and cognitive aspects of GIScience concern human knowledge and knowing involving geographic information and geographic information systems (GIS). It is practically motivated by the desire to improve the usability, efficiency, equity, and profitability of geographic information and GIS (Montello 2009). Mark and Frank 1991 is among the earliest collections of research papers that explicitly identifies itself as being concerned with cognitive aspects of GIS, and Egenhofer and Mark 1995 introduces the concept of "naïve" or "commonsense" geography, providing an influential theoretical rationale for studying lay people's conceptions of geographic phenomena as a way to improve GIS design. It specifically helped stimulate an approach to cognitive GIScience that focuses on *geo-ontologies*. An extension of the traditional metaphysical definition of ontology as the study of the ultimate nature of reality, geo-ontologies are understood as roughly equivalent to *conceptual system*s (GIScientists also use the term to represent formal models of these conceptual systems). Interest in ontologies stems from recognizing that digital representations of geographic information, such as in databases, are models of reality, not reality itself. At the same time, human understandings of features and events in the world constitute cognitive models of reality (see Mark 1993, cited under Spatial/Geographic Language), and because different individuals and groups may have different models of reality, researchers speak of "ontologies" in the plural. More generally, Peuquet 2002 provides the broadest overview of research in cognitive GIScience and ties it to noncognitive aspects, such as database issues. Raubal 2009 presents an overview of behavioral and cognitive issues for GIS, particularly informed by an engineering sensibility. Hirtle 2011 summarizes cognitive issues for GIS in a way that is particularly well informed by spatial cognition research findings. Richter and Winter 2014 also discusses cognitive approaches to GIS, focusing on implementing landmarks in navigation systems. At the same time that work over the past several decades has evinced enthusiasm for using cognitive science to improve GIS, Ishikawa 2019 adds to the accumulating evidence that the use of digital information systems can come with the cost of weakening human cognitive skills, a key example of *technological infantilism*.

Egenhofer, Max J., and David M. Mark. "Naive Geography." In *Spatial Information Theory: A Theoretical Basis for GIS*. Edited by Andrew U. Frank and Werner Kuhn, 1–15. Lecture Notes in Computer Science 988. Berlin: Springer, 1995.

Influential theory of "naïve" or "commonsense" geographic understanding, inspired by "Naive Physics Manifesto" of Patrick Hayes (in *Expert Systems in the Microelectronic Age*, edited by Donald Michie [Edinburgh: Edinburgh University Press, 1978], pp. 242–270), which called for artificial intelligence to focus on lay thinking instead of expert thinking about the physical world. Presents fourteen elements of naive geographic thinking, including that the world is flat. Very influential in the movement to improve GIS design by understanding lay people's understanding of geography.

Hirtle, Stephen C. *Geographical Design: Spatial Cognition and Geographical Information Science*. San Rafael, CA: Morgan & Claypool, 2011.

Thorough review of research on behavioral and cognitive issues in GIS design. Best available overview of relevance of spatial cognition for geographic information technologies, and vice versa.

Ishikawa, Toru. "Satellite Navigation and Geospatial Awareness: Long-Term Effects of Using Navigation Tools on Wayfinding and Spatial Orientation." ***The Professional Geographer*** **71.2 (2019): 197–209.**

Explores the idea that GPS-enabled navigation systems (nav-systems) have deleterious effects on people's abilities to maintain orientation and acquire survey cognitive maps. Provides important evidence that the effects are long term and that the correlation of nav-system use with spatial knowledge is a causal effect of system use rather than just the reverse causal effect of ability on deciding to use these systems.

Mark, David M., and Andrew U. Frank, eds. ***Cognitive and Linguistic Aspects of Geographic Space*****. Dordrecht, The Netherlands: Kluwer Academic, 1991.**

Original discussions of cognition, language, and behavior explicitly within the context of GIS. From a NATO workshop at Las Navas, Spain, the first major meeting on these topics within the GIS community. Now recognized as a progenitor of the research domain of cognitive issues in GIScience and the Conference on Spatial Information Theory (COSIT) series.

Montello, Daniel R. "Cognitive Research in GIScience: Recent Achievements and Future Prospects." ***Geography Compass*** **3.5 (2009): 1824–1840.**

Comprehensive overview of theoretical and empirical issues of cognition and behavior involving GIS in a broad sense. From a perspective of basic behavioral and cognitive science, with pointers to relevant applied issues.

Peuquet, Donna J. ***Representations of Space and Time*****. New York: Guilford, 2002.**

The most comprehensive review integrating cognitive, philosophical, computational, and database issues in GIScience.

Raubal, Martin. "Cognitive Engineering for Geographic Information Science." ***Geography Compass*** **3.3 (2009): 1087–1104.**

Overview of cognitive engineering research applied to improving technologies and tools that incorporate geographic information, especially location-based systems and services. Cognitive engineering is a human factors (ergonomics) approach emphasizing analysis of cognitive processes—such as perception, memory, and reasoning—involved in using systems and technologies.

Richter, Kai-Florian, and Stephan Winter. ***Landmarks: GIScience for Intelligent Services*****. Cham, Switzerland: Springer International, 2014.**

Comprehensive and authoritative review of the role of landmarks in geographic information systems, particularly navigation systems. Covers research that explores the role of landmarks and provides recommendations for their implementation in GIS.

Using and Comprehending Maps and Other Geographic Displays

As discussed in the Introduction, an interest in cartographic map perception and cognition has long been part of the field of behavioral and cognitive geography. Robinson 1952 laid out the argument to consider maps as tools for communicating ideas and information to people; as such, Robinson argued, maps should be studied with the help of the psychological sciences of perception and cognition. This led to a flowering of the research tradition of cognitive aspects of cartographic communication (details of the communication model for cartography are laid out in Board 1981). It became recognized that maps are systems of signs and symbols whose interpretation depends in part on a person's prior knowledge and learning experience. MacEachren 1995 provides a comprehensive review of the concepts and findings of research concerning the cognition of cartographic displays, and Fabrikant, et al. 2010 presents a strong modern example of empirical research linking the science of perception and cognition to map design. Petchenik 1983 provides an important critique of applying psychological science to cartographic design, however, although some of Petchenik's most important points have become moot with revisions to the traditional communication paradigm (revisions that her chapter helped to motivate). Hoffman and Markman 2001 looks at cognitive aspects of interpreting imagery from remote sensing. Beginning about three decades ago, research on geographic information

visualization (*geovisualization*) expanded from a traditional concern with graphical displays that are static, two-dimensional, and passively viewed to displays that are interactive, dynamic, multisensory (notwithstanding the term "*visualization*"), spatially three-dimensional, and more. Slocum, et al. 2001 presents overview research questions for cognitive research on geovisualization.

Board, Christopher. "Cartographic Communication." ***Cartographica*** **18.2 (1981): 42–78.**

Exposition of the influential communication model in cartography, which argues that maps work by encoding the cartographer's intended meaning into map symbols that are decoded more or less successfully by the map reader to extract the cartographer's message.

Fabrikant, Sara I., Stacy Rebich Hespanha, and Mary Hegarty. "Cognitively Inspired and Perceptually Salient Graphic Displays for Efficient Spatial Inference Making." ***Annals of the Association of American Geographers*** **100.1 (2010): 13–29.**

Thorough discussion of modern views on cognitive cartography and the design of geographic information displays by authors exceptionally well versed in both cartography and psychology. Applies psychological theory and empirical methods (particularly eye-movement assessment) to evaluate the role of perceptual salience in map design, with weather maps as an interesting case.

Hoffman, Robert R., and Arthur B. Markman, eds. ***Interpreting Remote Sensing Imagery: Human Factors*****. Boca Raton, FL: Lewis, 2001.**

Edited collection of research by perceptual, cognitive, and human-factors psychologists on the interpretation of remotely sensed images from optical and satellite remote sensing.

MacEachren, Alan M. ***How Maps Work: Representation, Visualization, and Design*****. New York: Guilford, 1995.**

Combines comprehensive summary of experimental perceptual and cognitive research on map design and interpretation with philosophical analyses based on map semiotics. Shows that the influential communication model in cartography is misleading because it does not capture the flexible and nondeterministic ways maps actually function cognitively. This is the best single source on cognitive map research.

Petchenik, Barbara Bartz. "A Mapmaker's Perspective on Map Design Research, 1950–1980." In ***Graphic Communication and Design in Contemporary Cartography*****. Edited by D. R. Fraser Taylor, 37–68. Progress in Contemporary Cartography 2. Chichester, UK: Wiley, 1983.**

Tour-de-force critique of cognitive map-design research from a student and colleague of Arthur Robinson's. Contrasts analytic goals of scientific research with synthetic goals of mapmakers. Questions the ability of research to accommodate the idiosyncratic nature of map users, map tasks, and map designs. Important in its recognition of the limits of the communication model in cartographic research.

Robinson, Arthur H. ***The Look of Maps: An Examination of Cartographic Design*****. Madison: University of Wisconsin Press, 1952.**

Based on the author's dissertation, this work championed the idea of understanding maps as tools for human perception and cognition, not just repositories of objective and consensual geographic knowledge. It paved the way for decades of research on map psychology and stimulated several nonbehavioral approaches to understanding maps and mapping from subjective and contextual perspectives.

Slocum, Terry A., Connie Blok, Bin Jiang, et al. "Cognitive and Usability Issues in Geovisualization." ***Cartography and Geographic Information Science*** **28.1 (2001): 61–75.**

Research agenda for cognitive and usability issues in geovisualization, organized into six major research themes. Assumes that traditional cognitive theory for static two-dimensional maps may not apply well to dynamic, interactive, and immersive three-dimensional representations.

Spatial/Geographic Language

Besides maps and other forms of imagery, geographic knowledge is also expressed verbally, in the form of written and spoken natural languages, such as English or Mandarin Chinese. Much of this work examines how spatial, temporal, and thematic knowledge is expressed in different languages, including Bloom, et al. 1996; Mark 1993; and Mark, et al. 2011. Spatiality can be expressed in nearly all grammatical classes, but prepositions, in particular, mostly convey spatial information. Researchers are interested in the precision and geometric sophistication of spatiality expressed in language, and the context-dependent nature of many spatial expressions, including deictic expressions such as “here” and “there,” discussed in Klein 1982, and terms concerning size or distance (“near,” “small”). Spatiality is conveyed in a variety of linguistic forms, including narratives (such as in stories) and verbal signage (Passini 1992, cited under Behavior and Cognition in Built Environments). The most common application area for the study of language in geography involves verbal route directions, addressed in Allen 1997 and Denis, et al. 2007. Questions about how language expresses spatiality inevitably lead one to confront a variety of long-standing philosophical and scientific questions about the relationship of language and thought (Bloom, et al. 1996). It is fascinating and noteworthy that the most common semantic domain in which this issue has been debated is that of spatiality (see Levinson 2003, cited undern Individual, Sex, and Cultural Differences; Palmer, et al. 2017).

Allen, Gary L. “From Knowledge to Words to Wayfinding: Issues in the Production and Comprehension of Route Directions.” In *Spatial Information Theory: A Theoretical Basis for GIS*. Edited by Stephen C. Hirtle and Andrew U. Frank, 363–372. Lecture Notes in Computer Science 1329. Berlin: Springer, 1997.

Illuminating exposition of behavioral, cognitive, and social interactional issues surrounding one of the most important application areas for the study of language in geography—producing and comprehending navigational route directions. The proceedings of an international conference, COSIT ’97, held at Laurel Highlands, PA, 15–18 October 1997.

Bloom, Paul, Mary A. Peterson, Lynn Nadel, and Merrill F. Garrett, eds. *Language and Space*. Cambridge, MA: MIT Press, 1996.

Large collection of chapters by several top language researchers from linguistics, psychology, anthropology, and cognitive science. Covers a broad array of topics concerning language and spatiality at several different scales. Papers presented at a conference of the same name held 16–19 March 1994 at Tucson, Arizona.

Denis, Michel, Pierre-Emmanuel Michon, and Ariane Tom. “Assisting Pedestrian Wayfinding in Urban Settings: Why References to Landmarks Are Crucial in Direction-Giving.” In *Applied Spatial Cognition: From Research to Cognitive Technology*. Edited by Gary L. Allen, 25–51. Mahwah, NJ: Lawrence Erlbaum, 2007.

Nice summary of an extended research program on the psychology of producing and comprehending route directions, focusing particularly on evidence for the claim that referring to landmarks when providing route directions is very beneficial to people, even essential.

Klein, Wolfgang. “Local Deixis in Route Directions.” In *Speech, Place, and Action: Studies in Deixis and Related Topics*. Edited by Robert J. Jarvella and Wolfgang Klein, 161–182. Chichester, UK: Wiley, 1982.

Organized and thorough exposition of the structure of direction-giving episodes, both for those giving and for those receiving route directions. Analyzes deictic references in route directions, linguistic expressions requiring some kind of extra-linguistic context for their interpretation. An example is the spatial context provided by places imagined when routes are orally described.

Mark, David M. “Toward a Theoretical Framework for Geographic Entity Types.” In *Spatial Information Theory: A Theoretical Basis for GIS*. Edited by Andrew U. Frank and Irene Campari, 270–283. Lecture Notes in Computer Science 716. Berlin: Springer-Verlag, 1993.

One of the earliest discussions of ontological issues for GIScience, particularly in the context of international geographic data standards, from the perspective of cross-linguistic variation in vocabularies for geographic features. Detailed comparison example of “lake,” “lagoon,”

“pond” in English and “lac,” “lagune,” “étang” in French. Proceedings of an international conference, COSIT ’93, held at Marciana Marina, Elba, Italy, 19–22 September 1993.

Mark, David M., Andrew G. Turk, Niclas Burenhalt, and David Stea, eds. *Landscape in Language: Transdisciplinary Perspectives*. Amsterdam: John Benjamins, 2011.

Chapters by geographers, anthropologists, linguists, and others summarizing research on how speakers of different languages, especially languages of preindustrial and Indigenous societies, refer to landscape features, including geomorphological, water, and other features. Emphasizes the variety of linguistic references and their potential relation to conceptual variation across languages.

Palmer, Bill, Jonathon Lum, Jonathan Schlossberg, and Alice Gaby. “How Does the Environment Shape Spatial Language? Evidence for Sociotopography.” *Linguistic Typology* 21.3 (2017): 457–491.

Recent theory and research on the language-thought debate that argues for the influence of local landscape features on the way spatial language is used in various cultural groups. Their “Sociotopographic Model” argues against the idea that cultural choices in language determine spatial thinking independent of the influence of physical environments in which cultural groups reside (as in Levinson 2003, cited under Individual, Sex, and Cultural Differences).

Environmental Attitudes and Decision Making

Behavioral and cognitive geographers are interested in emotional as well as behavioral and cognitive responses to environments and their features, including both spatial and thematic features. Cognition and behavior are functionally and experientially intertwined with affect and motivation. Our beliefs and knowledge influence, and are influenced by, what we feel and what we do. When looking at human-environment relations from a behavioral and cognitive perspective, emotional responses (affect, mood) are considered essential. Examples include aesthetic (beauty, preference) and dysphoric (stress, anxiety) responses to environments and environmental events. A simplifying analysis (some might say simplistic) identifies two main structural elements of emotional states: hedonic tone (evaluation) and arousal (activity level). A third dimension of potency (control) is sometimes included. For example, happiness and sadness express positive and negative hedonic tone, respectively; anger and sadness express high and low arousal, respectively; anger and fear express high and low potency, respectively. A key concept in this domain of study is *attitude*, which is a belief about something coupled with an affective evaluation of the implication of this belief. For instance, one might have an attitude about petroleum involving the belief that burning it as fuel contributes to climate change and a feeling of worry about this state of affairs. Besides being interesting in and of themselves, emotions and attitudes about environments are thought to have important implications for predicting and explaining many important human behaviors and experiences, such as migration (residential relocation), tourism, shopping, job satisfaction, health, and more.

Behavior and Cognition in Built Environments

Geographers are interested in built (cultural, anthropogenic) as well as natural environments, whether they be cities, wilderness areas, agricultural fields, nature preserves, factories, or college campuses. Modern research even includes the geography of indoor places in its purview, overlapping even more with architecture (Carlson, et al. 2010). Cognitive and behavioral responses to built and natural environments depend partially on the same physical characteristics of the environments, as proposed in Weisman 1981, even though there are some typical differences between the way people respond to the two classes of environments, as discussed in Hartig and Evans 1993 (cited under Environmental Aesthetics and Preference/Nature Psychology). Physical characteristics of environments include their ambient lighting, the appearance of their surfaces (textures, colors, surface reflectivity), the spatial structure of their path networks (as in *space syntax* in Hillier and Hanson 1984, with a brief user’s manual Bafna 2003), the patterns of their occluding structures and consequent open areas (discussed in Benedikt and Burnham 1985), their temperature and humidity, the ruggedness and ground support of their terrain, their flora and fauna, and so on. Variables such as these influence not only aesthetic judgments, but also feelings of privacy and fear, and the ease of orienting within them, as suggested in Passini 1992.

Bafna, Sonit. "Space Syntax: A Brief Introduction to Its Logic and Analytical Techniques." *Environment and Behavior* 35.1 (2003): 17–29.

Provides an introduction to the concepts and analytical techniques of research using space syntax. Although Hillier and Hanson 1984 devised the theory of space syntax, this article is still the only relatively clear and straightforward published "user's manual" for actually applying space syntax analysis, an increasingly popular activity in behavioral and cognitive geography, and many other disciplines.

Benedikt, Michael, and Clarke A. Burnham. "Perceiving Architectural Space: From Optic Arrays to Isovists." In *Persistence and Change: Proceedings of the First International Conference on Event Perception*. Edited by William H. Warren and Robert E. Shaw, 103–114. Hillsdale, NJ: Lawrence Erlbaum, 1985.

Presents the powerful idea that many cognitive and behavioral and cognitive responses, in both indoor and outdoor environments, are influenced by the size and shape of open areas or *isovists*, spatial extents available to direct visual access or lines of sight from a given point. Introduced by planners and architects, this idea is essentially the same as viewshed analysis in geography. Space syntax analysis has incorporated isovist analysis as a major component.

Carlson, Laura A., Christoph Hölscher, Thomas F. Shipley, and Ruth Conroy Dalton. "Getting Lost in Buildings." *Current Directions in Psychological Science* 19.5 (2010): 284–289.

Reviews theory and evidence concerning how the physical characteristics of interior built spaces, such as their appearance and layout geometry, combine with a person's knowledge, abilities, and cognitive strategies to determine the person's orientation and spatial learning in those spaces. Combines architectural theories with psychological theories to argue for an integrative framework involving all these factors.

Hillier, Bill, and Julienne Hanson. *The Social Logic of Space*. Cambridge, UK: Cambridge University Press, 1984.

Introduced the behavioral theory of the development of organic (unplanned) urban spaces. Also proposed the very rich and far-reaching analytic approach known as *space syntax* for analyzing topological patterns of paths, hallways, streets, and so on, with implications for pedestrian behavior, cognitive mapping, public sociality, and much more.

Passini, Romedi. *Wayfinding in Architecture*. 2d ed. New York: Van Nostrand Reinhold, 1992.

Architectural analysis of factors of physical environments, particularly built spaces, that influence wayfinding within the spaces. Especially strong analysis of role of signage. Applied focus on improving orientation in built spaces.

Weisman, Jerry. "Evaluating Architectural Legibility: Way-Finding in the Built Environment." *Environment and Behavior* 13.2 (1981): 189–204.

Influential typology of four physical characteristics of built environments (that also largely apply to natural environments) that are very useful for understanding how physical characteristics affect behavioral and cognitive responses in those environments, especially ease of orientation. Factors are differentiation of appearance, visual access, complexity of layout, and signage systems.

Environmental Aesthetics and Preference/Nature Psychology

As discussed in Hartig and Evans 1993 and Kaplan 1992, psychologists and others began to study aesthetics scientifically in the 1950s, focusing on formal properties of visual stimulus properties such as complexity, mystery, novelty, and coherence (so-called *collative properties*); later, these approaches were applied to environmental scenes. Other approaches focused more on the content of environmental scenes rather than just formal visual properties, and they tended to interpret the role of content in terms of human biological

evolution. That is, it was claimed that preferences for particular environments have evolved to reflect the functional significance of environmental properties for tasks such as hunting and gathering, wayfinding, locating mates, and avoiding predators. These considerations have been applied to explaining patterns of environmental preference seen universally (across cultures), even when assessed with ratings of photographs, as discussed in Daniel 1990. Some of the widely observed patterns include preference for natural over built environments and scenes with water over scenes without it; even built environments that visually appear more like natural environments are aesthetically preferred (Coburn, et al. 2019). Perceptual responses to natural scenes have also been investigated to understand the positive health and emotional benefits of exposure to natural environments (Ulrich 1984). The “savannah hypothesis” proposes that tropical savannah landscapes, with trees shaped in particular ways and distributed among partially open grassy areas, are maximally preferred across cultural groups, especially by children. Another important theory is “prospect-refuge theory,” which attributes aesthetic responses to environments as resulting from the way their layout and form facilitate seeing surrounding areas without oneself being visible. Savannah landscapes generally have good prospect and refuge, in fact.

Coburn, Alexander, Omid Kardan, Hiroki Kotabe, et al. “Psychological Responses to Natural Patterns in Architecture.” *Journal of Environmental Psychology* 62 (2019): 133–145.

Recent interesting theoretical discussion of the relationship of perceived “naturalness” in architecture to aesthetic judgments of the architecture. Perceived naturalness is proposed to result from aspects of the visual appearance of architecture tied to the two low-level perceptual variables of levels of scale (natural buildings have more elements at multiple spatial scales of size, hierarchically nested) and contrast (natural buildings have more elements that oppose or contrast with each other in appearance).

Daniel, Terry C. “Measuring the Quality of the Natural Environment.” *American Psychologist* 45.5 (1990): 633–637.

Overview of methods for systematically assessing aesthetic and other affective responses to natural environments. Traditional psychometric approaches (author calls them “psychophysical”) as well as newer alternatives are reviewed. Makes a strong case for the importance of measuring aesthetic responses as part of a valid and complete valuation of natural environments for policymaking.

Hartig, Terry, and Gary W. Evans. “Psychological Foundations of Nature Experience.” In *Behavior and Environment: Psychological and Geographical Approaches*. Edited by Tommy Gärling and Reginald G. Golledge, 427–457. Amsterdam: North-Holland, 1993.

Excellent review chapter covering basic definitional issues of natural versus built (cultural) environments, the role of nature in informational and affective responses to environments, and the potential benefits of nature experiences of various kinds, such as Outward Bound and viewing landscape paintings from a hospital bed.

Kaplan, Stephen. “Environmental Preference in a Knowledge-Seeking, Knowledge-Using Organism.” In *The Adapted Mind: Evolutionary Psychology and the Generation of Culture*. Edited by Jerome H. Barkow, Leda Cosmides, and John Tooby, 581–598. New York: Oxford University Press, 1992.

Another excellent review of environmental preference and aesthetics that focuses on affective and information-processing approaches in the light of human biological evolution. Among other issues, Kaplan carefully reviews his own “Attention Restoration Theory” for understanding how and why natural environments relieve stress and refresh attention, as well as the informational model of environmental preference by himself and Rachel Kaplan.

Ulrich, Roger S. “View through a Window May Influence Recovery from Surgery.” *Science* 224.4647 (1984): 420–421.

Groundbreaking and widely cited study on postoperative patients in hospital rooms with windows showing views of natural scenery recovering more quickly than matched controls in rooms with windows showing brick walls. Patients with the natural views stayed for shorter periods after their operations, received less negative evaluations in nurses’ notes, and took fewer strong painkillers.

Environmental Risks and Hazards

People also respond dysphorically to environments and environmental events—they see them as unattractive or they feel fear, anxiety, or even dread about them. This is addressed in behavioral and cognitive geography with research on environmental hazards. Geography has included the study of environmental hazards for over half a century, being exceptionally well suited as a discipline to recognize that all hazards emerge from an interaction of the natural, social, and technological—in every case (Burton, et al. 1978). (Geographers have traditionally referred to hazard or risk "perception" rather than cognition.) Much of the behavioral and cognitive work has focused on decision-making heuristics, simplified rules of thumb for assessing probabilities in uncertain situations, as discussed in Slovic 1993 and Breakwell 2007. One important issue has been a comparison of intuitive judgments about the occurrence and consequences of hazard events with the expert judgments of the formal discipline of risk assessment, which attempts objectively to identify, characterize, and quantify risk from hazard events. Also important are social implications of hazards, including the way societal and media responses to the possibility of hazards dampens or amplifies perceived risks, beyond what an objective assessment would predict. Research on environmental risks and hazards includes not only work on relatively discrete "events," but also on potentially hazardous conditions or states, especially behavioral and cognitive aspects of environmental change, such as pollution, deforestation, and climate change (Dunlap, et al. 2000; Leiserowitz 2006; Moser and Dilling 2006; Nickerson 2003; Stern 2000).

Breakwell, Glynis M. *The Psychology of Risk*. Cambridge, UK: Cambridge University Press, 2007.

Broad overview of behavioral and cognitive study of risk, particularly related to environmental events and conditions. Covers cognitive, affective, social, technological, and economic aspects.

Burton, Ian, Robert W. Kates, and Gilbert F. White. *The Environment as Hazard*. New York: Oxford University Press, 1978.

Overview of the geographic work on natural hazards going back to Gilbert White's seminal work of the 1940s and 1950s arguing convincingly that natural hazards like floods and droughts are never just "natural" but are always caused by human activities as well as natural events.

Dunlap, Riley E., Kent D. van Liere, Angela G. Mertig, and Robert Emmet Jones. "Measuring Endorsement of the New Ecological Paradigm: A Revised NEP Scale." *Journal of Social Issues* 56.3 (2000): 425–442.

Revised version of the most widely used survey instrument for assessing pro- and anti-environmental attitudes and values. The internally consistent and validated scale consists of fifteen self-report items, such as "Humans were meant to rule over the rest of nature" and "The balance of nature is very delicate and easily upset."

Leiserowitz, Anthony. "Climate Change Risk Perception and Policy Preferences: The Role of Affect, Imagery, and Values." *Climate Change* 77.1 (2006): 45–72.

Early research by the influential Yale Program on Climate Change Communication, started and overseen by Leiserowitz. Conducts large, high-quality surveys of lay respondents on many aspects of climate change, including its occurrence, causes, effects, need for remediation, and more. Drives home the message that attitudes about climate change are multifaceted, not just a matter of believing in it or not, and relate to a complex set of psychological and sociocultural factors.

Moser, Susanne C., and Lisa Dilling, eds. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*. Cambridge, UK: Cambridge University Press, 2006.

Edited collection that provides an early and still probably the best treatment of one of the major stumbling blocks humans face in dealing with anthropogenic climate change—effectively communicating what climate scientists know about it to lay people and policymakers. Chapter authors come from various academic disciplines as well as government and non-governmental organizations.

Nickerson, Raymond S. *Psychology and Environmental Change*. Mahwah, NJ: Lawrence Erlbaum, 2003.

Explores attitude assessment, attitude change, and the relationship between attitudes and behaviors in the context of environmentally relevant behaviors such as resource use, consumer behavior, support for policy, and voting. Explores the potential for behavioral and cognitive research to contribute to ameliorating problems arising from environmental change.

Slovic, Paul. "Perceptions of Environmental Hazards: Psychological Perspectives." In *Behavior and Environment: Psychological and Geographical Approaches*. Edited by Tommy Gärling and Reginald G. Golledge, 223–248. Amsterdam: North-Holland, 1993.

Reviews research on the psychometric paradigm for understanding hazard perception by lay people. Extended discussion of social amplification of risk and place stigmatization that can arise, presenting the author's research on the Yucca Mountain nuclear waste repository site in Nevada (which is no longer being considered for this purpose, after millions of dollars and decades of research).

Stern, Paul C. "Toward a Coherent Theory of Environmentally Significant Behavior." *Journal of Social Issues* 56.3 (2000): 407–424.

Reviews conceptual framework for understanding environmentally significant behaviors such as consumer choice, resource use, and voting. Focuses on theories involving attitudes, values, and norms, and includes recommendations for the design of programs to promote pro-environmental behavior.

Spatial/Geographic Development and Education

People's geographic knowledge varies as a function of their age, education, and experience. In other words, geographic knowledge depends on learning and maturation. Infants are born without specific geographic knowledge, although their nervous system is innately designed to acquire particular types of information (such as depth and directional relations) when exposed to the world through sensorimotor experience. As infants and children age, their geographic knowledge changes, because of changes to the nervous system, new experiences, and reorganizations of cognitive structures and processes that occur over time independent of specific experiences. Different theoretical approaches conceptualize development as occurring in relatively abrupt transitions between qualitatively distinct stages, or in relatively gradual and continuous transitions. These changes are both general, such as acquiring an understanding of spatial relations like hierarchical containment, and specific, such as acquiring an understanding of the layout of a particular neighborhood one has visited.

Spatial Behavior and Cognition in Children

Behavioral and cognitive geographers are interested in the behavior and cognition of children in space and place, both because adults become what they are in part because of their childhood experiences, and because children are people in and of themselves, and therefore of interest to human geographers. The single most influential work in this topical area comes from the Swiss child psychologist Jean Piaget (Piaget and Inhelder 1967), whose broad theory of cognitive development in all domains continues to influence geographers, psychologists, and other behavioral and cognitive scientists, even as alternative theoretical frameworks for understanding development continue to be proposed and evaluated. For example, Hart and Moore 1973 and Spencer, et al. 1989 discuss Piaget's theory and other ideas and empirical results as they apply to the development of spatial understanding of environments. The most authoritative work on the subject, Newcombe and Huttenlocher 2000 follows in this tradition but contrasts Piagetian work with newer scientific theories and findings. Hart 1979 focuses more on observations of children's behavior in space and place, providing a rich observational study of actual ongoing behavior in naturalistic environments. There has also been quite a bit of work on children's understanding—or lack thereof—of cartographic maps. Blaut, et al. 2003 presents the argument that mapmaking and map interpretation are culturally universal acts that emerge "naturally" in childhood without specific culturally dependent training. Liben and Downs 1989 counters this with an argument in favor of Piaget's approach. Uttal 2000 argues that the Western conception of maps is a product of a cultural tradition so pervasive that it even shapes people's way of thinking about space and spatiality in general.

Blaut, James M., David Stea, Christopher Spencer, and Mark Blades. "Mapping as a Cultural and Cognitive Universal." *Annals of the Association of American Geographers* 93.1 (2003): 165–185.

Summarizes logic and evidence for theoretical claim that mapmaking and map interpretation are culturally and historically universal human activities, which emerge "naturally" in childhood without specific cartographic training. Argues against the notion that map skills emerge gradually over childhood and adulthood, especially in stage-like progression, contrary to Piagetian claims.

Hart, Roger A. *Children's Experience of Place*. New York: Irvington, 1979.

Rich and extensive multi-method study of children's spatial activity and knowledge, place emotions, and use of space and place. Combines behavioral and cognitive observation, self-report diaries, and parent and child interviews. Combines scientific and humanistic approaches.

Hart, Roger A., and Gary T. Moore. "The Development of Spatial Cognition: A Review." In *Image & Environment: Cognitive Mapping and Spatial Behavior*. Edited by Roger M. Downs and David Stea, 246–288. Chicago: Aldine, 1973.

Sophisticated review of past theorizing and research on development of children's spatial thinking. Especially detailed exposition of hypothesized developmental sequence of spatial frames of reference, from egocentric to concrete allocentric to abstract allocentric.

Liben, Lynn S., and Roger M. Downs. "Understanding Maps as Symbols: The Development of Map Concepts in Children." In *Advances in Child Development and Behavior*. Vol. 22. Edited by Hayne W. Reese, 145–201. San Diego, CA: Academic Press, 1989.

Detailed theoretical framework explaining the gradual emergence of map interpretation skills over the life span, which involves acquiring particular cognitive skills at different ages. This development is characterized by typical misunderstandings about map symbols. It is consistent with Piaget, not with the "natural" mapping espoused for decades by Blaut and colleagues (e.g., Blaut, et al. 2003).

Newcombe, Nora S., and Janellen Huttenlocher. *Making Space: The Development of Spatial Representation and Reasoning*. Cambridge, MA: MIT Press, 2000.

Authoritative review of research on the child development of spatial thinking and reasoning in a variety of contexts, including in environments, with maps, in language, and so on, and from newborn infants to adolescents. Informed by Piagetian theory but updated with information-processing, nativist, and nonhuman animal perspectives.

Piaget, Jean, and Bärbel Inhelder. *The Child's Conception of Space*. New York: W. W. Norton, 1967.

The most influential body of work on the development of spatial cognition in children (originally published in 1948). Presents famous ideas of stage-like progressions dependent on interactions with the physical world, systematically changing schematic knowledge structures, and the resolution of typical misunderstandings in spatial reasoning tasks such as overcoming egocentric perspective, understanding metric geometry, and using coordinate systems.

Spencer, Christopher, Mark Blades, and Kim Morsley. *The Child in the Physical Environment: The Development of Spatial Knowledge and Cognition*. Chichester, UK: Wiley, 1989.

Overview of research on spatial cognition and behavior at environmental scales with children. Considers both basic and applied issues.

Uttal, David H. "Seeing the Big Picture: Map Use and the Development of Spatial Cognition." *Developmental Science* 3.3 (2000): 247–264.

Argues against map comprehension as culturally universal or “natural,” contrary to Blaut, Barbara Landau, and others. Also opposes Piagetian view that spatial understanding emerges asocially from interacting with the physical world. Looks at the role of culturally specific training and experience as critical, and argues that Western exposure to cartographic products molds a particular way of conceiving of space generally.

Spatial/Geographic Education

An applied reason for the geographer’s interest in geographical thought and behavior, and its development over the life span, is that it will help us understand how best to educate children and adults about spatial and thematic facts, concepts, theories, and methods of geography. An interest in geographic education is shared by many human and physical geographers, as well as educators and education researchers. This interest is part of behavioral and cognitive geography when it incorporates systematic behavioral and cognitive-science concepts and methods. Gersmehl and Gersmehl 2006 and Golledge, et al. 2008 elaborate on the claim that effective geographic education depends on a framework for understanding the basic concepts of geographic thought at various developmental levels (that is, they provide a developmental analysis of geographic ontologies; see Behavioral and Cognitive Aspects of Geographic Information Science). Vosniadou and Brewer 1992 exemplifies high-quality empirical research on geographic conceptual change. An important publication of the National Research Council (US), Committee on Support for Thinking Spatially 2006 focuses specifically on spatial components of geographic knowledge and the possibility that GIS technologies might be useful tools to promote such spatial understanding. Recently, a great deal of interest has focused on how training specifically in spatial thinking (one component of geographic thinking, albeit a central one) can potentially improve various intellectual skills, especially performance in science, technology, engineering, and mathematics (STEM) disciplines (Montello, et al. 2014; Uttal, et al. 2013).

Committee on Support for Thinking Spatially: The Incorporation of Geographic Information Science across the K-12 Curriculum, National Research Council. *Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum*. Washington, DC: National Academies Press, 2006.

A far-reaching examination of the value of explicitly incorporating spatial thinking into the educational curriculum at all levels, including the role of geographic information technologies in this effort. Appendix C provides an excellent discussion of individual, sex, and age-related variations in spatial cognition (see Individual, Sex, and Cultural Differences).

Gersmehl, Philip J., and Carol A. Gersmehl. “Wanted: A Concise List of Neurologically Defensible and Assessable Spatial-Thinking Skills.” *Research in Geographic Education* 8 (2006): 5–38.

An innovative call to base educational curricula on spatial thinking in geography on findings in cognitive neuroscience and the scientific study of mind-brain relations, especially recent advances derived from imaging brain activities with functional magnetic resonance imaging (fMRI).

Golledge, Reginald G., Merideth Marsh, and Sarah Battersby. “A Conceptual Framework for Facilitating Geospatial Thinking.” *Annals of the Association of American Geographers* 98.2 (2008): 285–308.

Extensive and empirically based analysis of the basic concepts underlying spatial thinking in geography, from beginning novice to advanced expert levels.

Montello, Daniel R., Karl E. Grossner, and Donald G. Janelle, eds. *Space in Mind: Concepts for Spatial Learning and Education*. Cambridge, MA: MIT Press, 2014.

An edited collection of chapters by researchers in several disciplines that discusses the role of spatial thinking in academic and nonacademic tasks, and the promise of educating children and adults in such thinking, both to improve spatial skills per se and to improve other skills that centrally involve spatial thinking, notably performance in STEM disciplines.

Uttal, David H., Nathaniel G. Meadow, Elizabeth Tipton, et al. "The Malleability of Spatial Skills: A Meta-analysis of Training Studies." ***Psychological Bulletin*** **139.2 (2013): 352–402.**

Important meta-analysis (quantitative research review) that integrates empirical results of over 200 studies exploring if and how much various types of psychometric spatial abilities can be improved with various kinds of training. A medium effect of training is confirmed that is both stable and transfers to other spatial skills. Implications for STEM education are discussed.

Vosniadou, Stella, and William F. Brewer. "Mental Models of the Earth: A Study of Conceptual Change in Childhood." ***Cognitive Psychology*** **24.4 (1992): 535–585.**

Excellent example of sophisticated research on conceptual systems in childhood relevant to geographic understanding.

Individual, Sex, and Cultural Differences

One of the important contributions the behavioral and cognitive approach has made to human geography is its recognition that people differ in many ways that have implications for mind and behavior in space and place. Furthermore, behavioral and cognitive geographers promote the systematic study of these variations. These variations exist most fundamentally at the level of the individual person, but they can be aggregated according to many different variables, such as sex, gender, ethnicity, social class, residential environment, intellectual abilities, educational background, language, and many more (age and education differences are discussed in Spatial/Geographic Development and Education). It is critical, however, to recognize that correlations between aggregation variables and geographic behaviors (and beliefs and emotions) are, by themselves, ambiguous with respect to causal explanation. The aggregation variable could cause variations in the behavior, the behavior could cause variations in the aggregation variable, or another factor or set of factors correlated to the aggregation variable could explain variations in behavior. This ambiguity is sometimes signaled by using terms like "sex-related" or "culture-related" in order to suggest that there is a nonrandom statistical relationship in the data, but the explanation for it is uncertain. Allen, et al. 1996; Hegarty, et al. 2002; and Kozlowski and Bryant 1977 focus on individual differences in spatial abilities at environmental scales. Voyer, et al. 1995 focuses on sex-related differences in spatial abilities on traditional paper-and-pencil tests, while Nazareth, et al. 2019 focuses on them in navigational tasks. Coutrot, et al. 2018 introduces a video game useful for innovative study of variations in navigational cognition from across places and cultures of our world. Golledge 1993 discusses the field of disabilities geography. Gladwin 1970 and Levinson 2003 consider cultural variations in thinking and talking about space and place.

Allen, Gary L., Kathleen C. Kirasic, Shannon H. Dobson, Richard G. Long, and Sharon Beck. "Predicting Environmental Learning from Spatial Abilities: An Indirect Route." ***Intelligence*** **22.3 (1996): 327–355.**

Compares individual differences in metric and nonmetric spatial tasks at environmental scales, as in spatial learning during navigation, to scores on traditional psychometric (pictorial) spatial tests. Done within the analytic framework of structural equation modeling, a technique for assessing causal relations with nonmanipulated variables (i.e., from nonexperimental studies).

Coutrot, Antoine, Ricardo Silva, Ed Manley, et al. "Global Determinants of Navigation Ability." ***Current Biology*** **28.17 (2018): 2861–2866.**

Early results from a very large-scale study of spatial cognition using the video game these researchers developed called "Sea Hero Quest." Users around the world download the application, and their performance on what is essentially a desktop virtual simulation of wayfinding and spatial knowledge acquisition becomes data for the researchers. This early paper focuses on cultural and locational differences among users from across the globe, based on a sample of 2.5 million people from every country on Earth. Research with Sea Hero Quest is attracting a great deal of attention in prominent academic literature as well as popular media.

Gladwin, Thomas. ***East Is a Big Bird: Navigation and Logic on Puluwat Atoll*****. Cambridge, MA: Harvard University Press, 1970.**

Fascinating classic in anthropology examining a highly refined expert navigation system from a preindustrial culture in Micronesia. In addition to richly perceiving environmental cues, these navigators employ an intriguing “etak” system, dependent on mentally keeping track of distances traveled over the open ocean by reference to nonvisible or even imaginary islands.

Golledge, Reginald G. “Geography and the Disabled: A Survey with Special Reference to Vision Impaired and Blind Populations.” *Transactions of the Institute of British Geographers* 18.1 (1993): 63–85.

Considers the spatial behavior and cognition of populations with disabilities, including intellectual disabilities, mobility impairments, and, especially, visual impairments. Helped originate the field of disabilities geography.

Hegarty, Mary, Anthony E. Richardson, Daniel R. Montello, Kristin Lovelace, and Ilavanil Subbiah. “Development of a Self-Report Measure of Environmental Spatial Ability.” *Intelligence* 30.5 (2002): 425–447.

Following up and expanding on Kozlowski and Bryant 1977, these authors developed a valid and reliable self-report scale known as the “Santa Barbara Sense-of-Direction” scale. Sense of direction is an environmental spatial ability most strongly related to survey spatial knowledge ability, such as applied in creative wayfinding.

Kozlowski, Lynn T., and Kendall J. Bryant. “Sense of Direction, Spatial Orientation, and Cognitive Maps.” *Journal of Experimental Psychology: Human Perception and Performance* 3.4 (1977): 590–598.

Demonstrates the surprising reliability and predictive validity of a simple self-report of sense of direction (“How good is your sense-of-direction?”) as an efficient measure of environmental spatial ability, such as that involved in maintaining orientation during travel.

Levinson, Stephen C. *Space in Language and Cognition: Explorations in Cognitive Diversity*. Cambridge, UK: Cambridge University Press, 2003.

Extensive research program demonstrating cultural variation in spatial language and thought, particularly with respect to the implications of linguistically referring to directions with egocentric (relative) or abstract allocentric (absolute) reference systems (see also Spatial/Geographic Language).

Nazareth, Alina, Xing Huang, Daniel Voyer, and Nora Newcombe. “A Meta-analysis of Sex Differences in Human Navigation Skills.” *Psychonomic Bulletin & Review* 26 (2019): 1503–1528.

Over the past several decades, hundreds of experimental and nonexperimental studies have examined sex differences in a variety of spatial thinking skills, including wayfinding and spatial knowledge acquisition. Many find male superiority at these skills, but quite a few find little or no difference; females are almost never found to excel at these particular skills (although they do apparently excel at static object-location memory). This paper reports a meta-analysis of over 250 studies reporting comparisons of females and males on various navigation-related tasks, finding a small to medium effect size supporting a male advantage.

Voyer, Daniel, Susan Voyer, and M. Philip Bryden. “Magnitude of Sex Differences in Spatial Abilities: A Meta-analysis and Consideration of Critical Variables.” *Psychological Bulletin* 117.2 (1995): 250–270.

Comprehensive review of hundreds of studies on the magnitude, consistency, and stability of sex-related differences in psychometric spatial abilities. Applies meta-analysis to systematically combine statistical results from the studies. Supports existence of a male advantage in some of these abilities, especially mental rotation, but not all.

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