

## ARTICLE WITH PEER COMMENTARIES AND RESPONSE

# Seeing the big picture: map use and the development of spatial cognition



David H. Uttal

Northwestern University

### Abstract

*This paper considers the relation between the development of spatial cognition and children's use of maps and models. A new theoretical perspective is presented that takes into account the influences of maps on the development of spatial cognition. Maps provide a perspective on spatial information that differs in important ways from the perspective gained from direct experience navigating in the world. Using and thinking about maps may help children to acquire abstract concepts of space and the ability to think systematically about spatial relations that they have not experienced directly. In addition, exposure to maps may help children to think about multiple spatial relations among multiple locations. The results of previous studies that have demonstrated developmental differences in children's cognition of large-scale environments are examined from this theoretical perspective. This review suggests that the development of spatial cognition consists partly of the acquisition of models of large-scale space, and that maps influence the development of the modern Western model.*

While making one of his first orbits of the earth, John Glenn said, 'I can see the whole state of Florida laid out just like on a map' (Wilford, 1981). Glenn was referring to the unique perspective that one can gain by viewing the earth from space. Looking down at the earth allows us to see spatial information, such as the layout of an entire state, that can be almost impossible to perceive directly while navigating.

Although Glenn's observations were about traveling in space, his comments are also a testimony to the importance of maps. Like space travel, maps provide a perspective that can be difficult to acquire from direct experience navigating in the world. Moreover, maps can alter how we think about the represented information. For example, we may realize from looking at a map that our hometown is much closer to, or farther from, another city than we previously thought. Maps allow us to transcend our direct experience of the world and think systematically about relations among multiple locations (Downs & Liben, 1993; Wood, 1992; Liben, 1999).

The purpose of this paper is to present a new perspective on the development of children's conceptions

of large-scale space that considers the influences of maps and other external representations of space. The central thesis is that the development of mental representations of large-scale space is affected by the symbolic representation of spatial information on maps (Cassirer, 1944; Cassirer, Mannheim & Hendel, 1965; Ong, 1982; Liben & Downs, 1989, 1992; Olson, 1994; Hutchins, 1995; Liben, 1999, in press). Several ways in which the use of maps could influence the development of spatial cognition are discussed, and cross-cultural, historical and developmental evidence concerning the effects of maps is presented.

### Overview

My claims are based on the assumption that the relation between maps and the development of spatial cognition is reciprocal in nature (Liben & Downs, 1989, 1991; Gauvain, 1993, 1995; Liben, 1999, in press). As children acquire new and more sophisticated ways of mentally representing and using spatial information, their understanding of maps improves. Likewise, children's developing conception of maps affects how they understand

Address for correspondence: Department of Psychology, Northwestern University, 2029 Sheridan Road, Evanston, IL 60208-2710, USA; e-mail: [duttal@northwestern.edu](mailto:duttal@northwestern.edu)

and conceive of spatial information. In the words of Liben and Downs (1991), 'the particular place representations encountered – just like the particular 'real' environments encountered – will shape environmental knowledge and, relatedly, behavior' (p. 147).

Researchers have investigated children's understanding and use of a variety of external spatial representations, ranging from real geographic maps to simple scale models. Although these various symbolic representations differ in important ways, they all share an important similarity: each stands for a particular place, or set of places, in the world. This work has shown that, by the age of 3, young children can understand some of the basic, symbolic relations between maps or scale models and the referent spaces (DeLoache, 1987, 1989, 1991, 1995; Dow & Pick, 1992). However, young children have much more trouble acquiring or using more complex spatial information from maps. For example, 3-, 4- and 5-year-olds often cannot discriminate the location of objects in a space solely on the basis of the locations of the objects on a map. In addition, children of this age often have difficulty interpreting and using scale relations (Presson, 1982; Liben & Downs, 1992, 1993; Blades & Cooke, 1994; Blades & Spencer, 1994; Uttal, 1994, 1996; Liben & Yekel, 1996; Bence & Presson, 1997).

The difficulties that young children experience in understanding some elements of maps have been attributed, in part, to limitations in encoding, remembering or understanding the relevant spatial concepts. On this view, children's limitations in understanding maps are caused by limitations in the processing or representation of spatial information. My goal here is to show that the opposite may also be true – children's limitations in thinking about spatial information may reflect a lack of understanding of the functions and uses of maps. Learning about maps therefore may influence the development of spatial cognition.

In one sense, the notion that our conceptions of the world are influenced by the representation of the world on paper (i.e. on maps) is quite familiar. All maps distort spatial information because it is impossible to capture all aspects of a three-dimensional world on a two-dimensional sheet of paper. People's conceptions of the relevant areas often reflect these distortions. For example, because the representation of Greenland is distorted on standard Mercator projections, many people believe that this island is much larger than it really is. These kinds of errors highlight that our conceptions of large-scale space are influenced by the representation of information on maps (see Tversky, 1981).

I argue here that there is also a second and more general sense in which maps influence thinking about

spatial information: exposure to maps may help to instantiate a mental model or conception of large-scale space. This conception differs fundamentally from how space is experienced when navigating in the world. For example, the map-influenced conception of space is more abstract and less tied to direct experience of specific spaces. Many of the changes that have been observed in the development of children's cognition of the large-scale environment may stem from the acquisition of the map-influenced conception of the world.

This paper is organized into eight major sections. The sections focus respectively on the following issues: (a) definitions and restrictions of scope; (b) the theoretical background for the claim that maps influence how people think about space; (c) the acquisition of spatial information from maps; (d) the cognitive consequences of acquiring spatial information from maps; (e) cross-cultural and historical evidence; (f) previous characterizations of the development of large-scale spatial cognition; (g) research evidence that supports the claim that exposure to maps affects the development of spatial cognition; and (h) suggestions for testing the theory.

## Definitions and restrictions of scope

The term map has been used in numerous ways in several different fields of study, including biology, psychology, geography, mathematics and many others. The variety of definitions can lead to substantial confusion (Liben & Downs, 1991). The focus here is primarily limited to what Liben and Downs (1991) have called *prototypical maps*. These include maps shown in common atlases, road maps, and the kinds of maps that regularly appear on the walls of school classrooms. More specifically, I am focusing on the cognitive and developmental consequences of exposure to maps that represent spaces from an overhead or oblique view and that follow specific projections. Projection refers to the use of geometric techniques to capture some (but not all) aspects of the spherical shape of the earth on flat, two-dimensional paper. Although all projections necessarily involve distortions of either area or distance (Dent, 1996), they all follow spatially metric, Euclidean rules for making the compromises between preserving shape and distance information. Other kinds of maps may also affect the development of spatial cognition, but prototypical maps may have a particularly strong influence on how children's thinking about spatial information develops.

There is also a limitation on the scale of space that is discussed. Much of the focus here is on spatial cognition of environments that are typically larger than can be perceived in a single glance. This includes the space just

beyond one's current vista as well as regions, countries and the entire world (Spencer, Blades & Morsley, 1989; Montello, 1993; Montello & Golledge, 1999). Smaller spaces, such as a tabletop, are not a primary focus because maps typically are not used to learn about spaces of this size.

## Theoretical background

The present theoretical perspective is consistent with previous research in psychology, philosophy and geography. Many researchers have suggested that the ways in which information is represented symbolically may influence how people think about the represented information (Cassirer, 1944; Vygotsky, 1962, 1978; McLuhan, 1964; Luria, 1976; Downs, 1981; Ong, 1982; Eliot, 1987; Lave, 1988; Liben & Downs, 1989, 1993; Miller, 1989; Karmiloff-Smith, 1992; Vosniadou & Brewer, 1992; Gauvain, 1993; Olson, 1994; Hutchins, 1995; Miller & Paredes, 1996; Crosby, 1998; Liben, 1999). Examples come not only from research on children's use of maps, but also from research on other symbol systems.

One relevant example concerns the influence of literacy on metalinguistic awareness. Becoming literate may influence cognitive development in general and metalinguistic awareness more specifically. Even though young children may be able to use complex grammatical structures from an early age, they remain relatively unaware of the formal analysis of language until they are asked to read and write (Karmiloff-Smith, 1979, 1990, 1992; Bialystock, 1993, 1995; Olson, 1994; Lee & Karmiloff-Smith, 1996). The acquisition of literacy may be responsible, at least in part, for the development of explicit knowledge of grammar, sentence structure, and other aspects of language (Olson, 1994, 1996).

A second set of relevant examples comes from the domain of mathematics development. For instance, several researchers have suggested that learning about the written representation of zero (0) influences the development of concepts of nothingness (Wellman & Miller, 1986; Olson 1996). Similarly, experience in using fractions helps children to acquire a concept of division (Stern, 1993; Staub & Stern, 1997). Likewise, learning to use an abacus presents an alternative model of numerical representation that is partly visual-spatial and is based on the base-5 number system (Stigler, 1984; Stigler, Chalip & Miller, 1986; Miller & Stigler, 1991). Like written language, mathematical symbols bring into consciousness information that would otherwise remain opaque or inaccessible (Bialystock & Codd, 1996).

The influence of maps and other external representations of spatial information may be analogous to the

influence of other symbol systems on cognitive development. Perhaps the most general characteristic of maps is that they allow us to acquire, inspect and think about spatial information irrespective of navigation. Children may possess the ability to represent spatial information mentally in metric terms at an early age (e.g. Landau, 1986; Bushnell, McKenzie, Lawrence & Connell, 1995; Newcombe, Huttenlocher & Learmonth, in press), but this does not mean that they understand, or have explicit access to, knowledge of space *per se*. The understanding that space exists independent of our experience of it may come about as a result of exposure to maps. In addition, maps affect *how* we think about spatial information; maps may lead people to think about space in more abstract and relational ways than they would otherwise. For these reasons, maps can be construed as *tools for thought* in the domain of spatial cognition (Vygotsky, 1978; Liben & Downs, 1993; Miller & Paredes, 1996; Staub & Stern, 1997; Liben, 1999, in press). Maps provide a cognitive tool that helps children extend their reasoning about space in a new way. Over time, children can internalize the tool and think about space in map-like ways, even if they are not looking at a map at the time.

The present analysis is not meant to imply that exposure to maps is the only influence on the development of spatial cognition or that the course of the development of large-scale spatial cognition is totally open to the influences of maps. Other factors, including the nature of a person's experience, biological constraints and motivation may affect the development of spatial cognition. My claim is that the influence of maps is sufficiently great to merit a detailed consideration.

## Acquiring spatial information from maps

In this section, I consider several ways in which acquiring knowledge from maps could influence what we know about the represented information. Maps help us to conceive of the world beyond immediate experience, they make different kinds of information perceptually available, and they depict spatial information in an abstract way.

*Maps help us to conceive of the world beyond immediate experience*

The most general characteristic of maps regarding the acquisition of spatial information is that they make us aware of the world beyond what we have experienced. Maps allow us to look at, and study, sets of spatial relations without actually navigating through the space.

In Wood's (1993) words, 'this, essentially is what maps give us, *reality*, a reality that exceeds our vision, our reach, the span of our days, a reality we achieve no other way' (pp. 4–5). Coming to know the world through the mediated view of maps may provide an important inroad into realizing that there are alternative ways of thinking about, and mentally representing, the world beyond one's own experience. Of course, the reality that maps provide is not a faithful copy of the world because all maps distort the information that they represent.

*Maps make different kinds of information perceptually available*

The effects of maps are not limited only to helping us learn that there is a world beyond our immediate experience. Maps also influence *how* we acquire spatial information. Learning about space from a map differs in important ways from learning about space from navigation (Thorndyke & Hayes-Roth, 1982; Presson, Hazelrigg & DeLange, 1987; Tversky, 1996). During navigation, we constantly change the relation between where we are in space and what we are viewing (Tversky, 1996). Different features of the environment, including landmarks, alternative routes and so forth, continuously come in and out of view. In contrast, maps provide a more static view of space because substantial portions of a map can be inspected in a single glance (Blaut, 1991; Hutchins, 1995). Furthermore, the oblique or overhead point of view from which maps are typically read provides a very different perspective than we can usually gain from navigation. Moreover, because maps depict space at a relatively small scale, they can *decrease* the salience of individual features. Looking at the depiction of a particular landscape feature on a map may reveal less about the characteristics of the individual feature but more about the relation between this feature and other features.

Taken together, these characteristics of maps allow us to gain visual access to a greater number of spatial relations than would be available from direct experience. Even if one's primary focus is simply to plan a route between two locations, the representational format and scale of the map will probably bring other nearby locations into view, which can then become a focus of attention and thought. Maps thus can facilitate the *discovery* of new information (Hutchins, 1995; Liben, 1999). For example, one can immediately acquire a sense of the spatial relations among the major cities in the USA by looking at Figure 1. Information about relations among multiple locations can be extremely difficult to gain from navigation, but maps, charts and graphs make this information readily available (Larkin



**Figure 1** A map of the (approximate) relative positions of major cities in the USA. The map highlights relations among locations.

& Simon, 1987; Gentner & Ratterman, 1991; Shin, 1994; Uttal & Gentner, 1995; Allwein & Barwise, 1996; Gattis & Holyoak 1996). Knowledge of relations among locations may be particularly important when we are asked to reason about directions among multiple locations or to plan alternative detour routes.

*Maps highlight abstract space*

Another important characteristic of prototypical maps is that they rely upon a geometry that is based on an *abstract* conception of space (Eliot, 1987; Jammer, 1993). An abstract conception of space assumes that space continues to exist independent of the objects that are contained within the space. Thus, space *per se* can become an object of discussion and thought, and it can be described and measured. Concepts such as kilometers, latitude, longitude etc. all imply an abstract model of space (Crosby, 1998).

That prototypical maps highlight abstract notions of space may play a particularly important role in the development of spatial cognition. As will be discussed below, one of the prevailing characteristics of young children's spatial thought is that they tend not to conceive of space in this abstract, formal way. Instead, young children know about a large-scale space primarily in terms of the particular locations that they have experienced directly. Exposure to maps therefore may play an important role in helping children to think about space in abstract ways.

In sum, maps bring into view spatial and geographic information that would otherwise remain opaque or inaccessible from direct visual experience, and moreover they facilitate thinking about the represented information. In addition, they highlight particular kinds of

information, such as relations among locations. In the next section, I consider how these characteristics of maps might influence people's conceptions of large-scale space.

### Cognitive consequences of map use

Taken together, the characteristics of maps that were discussed in the previous section may lead to the creation of a particular model of large-scale space. The map-influenced model may affect both how we think about spaces we already know and how we acquire information about new spaces. When adults enter a new city, they may carry with them not only actual maps but also the awareness of the possibility of 'mapping out' the city mentally. For example, knowledge of maps might provide a model that helps adults to think about locations in terms of distances, angles and multiple relations among multiple locations. In essence, experience with maps gives adults a framework of absolute space that they can use as they acquire information about new locations.

Indeed, the influence of maps and other external spatial representations can be so strong that they directly influence how we interpret reality. Hutchins (1995) provides an example from the domain of ship navigation. Navigators sometimes come to prefer the information that they gain from charts or maps over the information they gain from their own direct experience. Modern navigators,

invest the interpretations of events in the domain of the representations with a reality that sometimes seems to eclipse the reality outside the skin of the ship. One navigator jokingly described his faith in the charted position by creating the following mock conversation over the chart: 'This little dot right here where these lines cross is where we are! I don't care if the bosun says we just went aground, we are here and there is plenty of water under the ship here.' For the navigator, the ship is where the lines of position intersect. (Hutchins, 1995, p. 115)

It is important to note, however, that the *possibility* of thinking about space in map-like terms does not mean that adults' representations of space are always map-like in nature. Several researchers (e.g. Kuipers, 1982; McNamara, 1986; Tversky, 1993, 1998; Shelton & McNamara, 1997) have consistently shown that not all spatial judgments require a map-like, abstract model of the spatial world. In particular, everyday navigation in familiar environments may well be accomplished by using representations that are organized around routes

and landmarks. I do suggest, however, that the map-influenced model of the world gives adults the *possibility* of thinking about space in formal, map-like terms. The map-influenced model is useful in particular tasks, including those used by Piaget and others used to assess children's knowledge of the large-scale environment.

The influences of maps on spatial cognition and its development could operate in both a specific and a general way. At the more specific level, working with maps gives people direct experience in thinking about space in map-like ways. However, the effect need not be limited to situations in which actual maps are physically present. Over time, people may form mental models of large-scale space that are influenced by the accumulation of experience in working with maps. Maps and other symbolic representations leave their mark on cognitive processing, even after the actual symbols are removed (Miller & Paredes, 1996).

In sum, the way in which adults in modern Western societies conceive of large-scale spatial information may be affected by how this information is represented on formal maps. In the next section, I consider cross-cultural research that is consistent with this claim.

### Cross-cultural and historical research on mental conceptions of large-scale space

An important implication of the present theoretical perspective is that there may be cross-cultural differences in how geographic-scale information is represented and used. My claim has been that prototypical maps influence the development of concepts of large-scale space. If this is true, then individuals who are reared in cultures that are less influenced by prototypical maps may have very different conceptions of large-scale space. Research in several non-Western cultures does suggest that the map-influenced model of geographical-scale space is not universal. Alternative conceptions of large-scale space that are less influenced by maps are often extremely sophisticated and support very impressive feats of navigation (Gell, 1983; Hutchins, 1995). Yet, they are distinctly different from modern Western (map-influenced) conceptions of large-scale space. Examining these differences highlights the effects of maps on Western conceptions of space. 'That this [i.e. modern, Western] representation of the world is a paper world, not an intuitive one, may be shown by contrasting this representation with others which are equally impressive but which are not based on maps and charts but on personal knowledge' (Olson, 1994, p. 213).

Perhaps the best documented example concerns the navigators of the Caroline Islands in the Pacific Ocean.

As Gladwin (1970), Lewis (1972) and Hutchins (1995) have noted, these individuals are able to navigate across hundreds of miles of open ocean without reference to maps or compasses. The native navigators' conceptions of space are fundamentally different from the Western, map- or chart-influenced conceptions. They imagine themselves to be part of the space. The position of the canoe is assumed to be fixed, and the navigators imagine that the stars and islands float past it. In contrast, modern, Western navigators conceive of space from above, as something that can be looked down upon and inspected, partly because of their experience in using maps (Hutchins, 1995).

A second well-documented example of sophisticated navigational abilities that are not based on the traditional Western map-like conceptions of space concerns groups of aborigines in Central and Western Australia. These individuals can travel across hundreds of miles of seemingly featureless desert, often without reference to compasses, maps or stars (Lewis, 1976; Chatwin, 1987; Berndt & Berndt 1994). In part, the navigation is accomplished by giving even small features of the desert symbolic meaning. Each navigator possesses an individual *songline*, a record of the individual's personal cosmology. Songlines connect locations in terms of myths regarding events, or *dreamings*, that took place during the creation of the particular features. One songline might include, for example, the story of the creation of a particular rock and the path that an ancient ancestor followed during the creation. In essence, the aborigines possess a very rich set of mnemonics that can provide a basis for recalling a route. When the individual goes on walkabout, he or she re-creates the record of the dreamings. The individual creation myths thus provide a rich set of landmarks that can facilitate navigation.

The aboriginal model of large-scale space is fundamentally different from the Western, map-influenced model. The aborigines do not conceive of their journeys in terms of fixed, metric distances. Rather, they remember and describe the journeys in terms of progress along a particular songline. As in the previous example regarding the Pacific navigators, the aborigines are able to navigate successfully without recourse to the Western, map-influenced model of large-scale space.

Finally, it should be noted that the Western, map-influenced model has evolved historically. Although maps have existed for perhaps as long as writing (Wilford, 1981), they were not readily available to the average person until they could be mass-produced (Brotton, 1998). In addition, abstract projections are a relatively new invention, and the map-influenced model of space may also be relatively new. Many early maps

and navigational charts were essentially listings of possible sailing routes with detailed descriptions of shorelines (Wilford, 1981; Hutchins, 1995; Brotton, 1998; Crosby, 1998). In short, the historical existence of some types of maps for millennia does not imply that the modern, map-influenced model of space has existed for the same amount of time. Ong (1982) has summarized the changes that were brought about historically by adopting the map (gradually) as a model for large-scale space:

Only after print and the extensive experience with maps that print implemented would human beings, when they thought about the cosmos or universe or 'world', think primarily of something laid out before their eyes, as in a modern printed atlas, a vast surface or assemblage of surfaces (vision presents surfaces) ready to be 'explored'. The ancient oral world knew few 'explorers', though it did know many itinerants, travelers, voyagers, adventurers, and pilgrims. (p. 73)

Although this section has focused on cross-cultural and historical differences in conceptual models of the world, there is also a general similarity among individuals from a wide variety of cultures. People in many different cultures *impose* on the external world a structure or mental model that leads to systematic organization and prediction. In modern Western societies, this model is engendered in part by exposure to maps. In non-Western societies, the model may be fundamentally different and is related to the cosmology of each culture. In both cases, however, people project a mental model onto the world and their experience of it (see Vosniadou & Brewer, 1992). Development may consist in part of the acquisition of the model that is relevant in a child's own culture.

The analysis presented thus far suggests that (a) adults in modern Western societies conceive of large-scale space partly in terms of a map-influenced model, but (b) this model is neither culturally nor historically universal. These two observations motivate the central claim of the next section: that the development of cognition of large-scale space in modern Western societies consists in part of the acquisition of a map-influenced model of the world.

### **Previous characterizations of the development of large-scale spatial cognition**

In this section, I consider previous characterizations of the development of large-scale spatial cognition and point out how exposure to maps might influence this development. Many researchers have demonstrated that

there are developmental differences in how children conceive of and mentally represent large-scale spatial information. For example, Piaget (Piaget & Inhelder, 1956; Piaget, Inhelder & Szeminska, 1960) suggested that young children's representations are based exclusively on topological relations and hence do not capture metric information such as angles and distance. Thus, on this view, the development of spatial cognition consists in part of the acquisition of new ways of mentally representing spatial information.

The results of more recent work on the development of children's mental representations of spatial information have led to an apparent paradox. On the one hand, the results of several studies suggest, contrary to Piaget's claims, that very young children can represent spatial information in sophisticated ways at a early age (Landau, 1986; Huttenlocher, Newcombe & Sandberg, 1994; Bushnell *et al.*, 1995; Newcombe & Huttenlocher, 2000). For example, Bushnell *et al.* (1995) found that 12-month-olds could find an object that was hidden under one of more than 50 irregularly shaped cushions in a large, circular hiding space. Curtains were placed around the border of the search space, and consequently there were no salient landmarks that the children could use as cues to the location of the object. These and similar results (e.g. Huttenlocher *et al.*, 1994) have been difficult to explain without claiming that the children have accurately encoded (metric) distance information that specifies the location in terms of a specific distance. Such a finding suggests that children do possess the ability to encode locations in metric terms much earlier than Piaget and others have claimed (Bremner, 1993).

Yet, despite these demonstrations of very early representation of metric information in young children, other researchers have observed substantial developmental differences in children's spatial cognition. In many cases, these developmental differences have been found in tasks that involve the cognition of large-scale space and multiple relations among multiple locations (Huttenlocher & Newcombe, 1984). It is these developmentally advanced skills, I will argue, that are affected in part by exposure to, and familiarity with, the model of space that children may gain from maps. Beginning in the late preschool years (approximately age 4 or 5), children undergo a shift in their conceptions and representations of large-scale space. Their knowledge of spatial relations becomes more abstract, and they start to think about space in terms of multiple relations among multiple locations. At approximately the same time, children begin to grasp how maps represent the large-scale world (Liben, 1999). Their understanding gradually develops throughout kindergarten and the

early elementary school years. I argue here that the growing awareness of maps could be a partial cause of the observed changes in children's spatial cognition. This is not meant to imply, however, that simply looking at a map once or twice would be sufficient to improve performance. The map-mediated conception of space develops gradually. Simple exposure to a map or two is unlikely to be sufficient. Instead, the developmental process that is implied here is likely to be gradual and involve a conceptual change (e.g. Carey, 1985).

In the remainder of this section, I consider three characteristics of young children's spatial cognition that may be related to their lack of exposure to or understanding of maps: the lack of an abstract concept of space, difficulties in acquiring or using survey knowledge, and poor performance in tasks that require thinking about large-scale space.

#### *Young children lack an absolute conception of space*

Some theorists, most notably Piaget and colleagues, suggested that only older children and adults think about large-scale space in absolute terms (Piaget & Inhelder, 1956; Piaget *et al.*, 1960). On this view, young (preoperational) children's conceptions of space are fundamentally relative; they think about spatial locations in terms of how they have experienced the locations personally (Bremner, 1993).

Two examples from the work of Piaget *et al.* (1960) highlight differences in younger and older children's conceptions of large-scale space. The examples are derived from a task in which children were asked to make small-scale models of the locations of local landmarks; they were asked to arrange the objects to form a plan of their town. The descriptions of two younger children's placements highlight that the reconstructions are not constrained or influenced by an absolute conception of space:

Miu (6; 10) puts a number of places together in what appears to be a pell-mell arrangement: the buildings and corridors of the main school, the main school playground, the kindergarten playground and entrance, the gymnasium which is a separate building, and a mound of sand on the bank of the Arve ... In short, a number of places are brought together by Miu's personal interest, while others show confusion between conceptual similarity and proximity in space. (p. 9)

Gei (5; 11) puts the main school near the kindergarten with the two adjoining playgrounds in between, which is correct. However, while a nursery and various other buildings which have no particular interest for him

find their right place by the main school building, places which fascinate him: the football ground and 'that house with the candy presents' (a general store which sells toys) are put near his own school – because they are near to his heart. (p. 9)

Piaget noted that, within a few years, children's placements of the objects were much more systematic and organized. In describing children of approximately ages 8–10, Piaget *et al.* noted that there was

a marked difference between these reactions and those of subjects at lower levels. In the first place, a topographical schema is planned from the outset as a single whole and even where a subject deals with it in separate sub-groups or adds a section to his drawing, he wastes no time in making the different parts agree with each other...The end-result is always a coordinate whole ... (p. 20)

Two aspects of the younger children's performance are noteworthy in terms of the potential influences of maps on spatial cognition. First, the reconstructions were not based on an abstract concept of space. Instead, the reconstructions reveal a relative concept of space, in which the children's personal experience is paramount. The younger children knew locations primarily in terms of what they had experienced directly or what was of special interest to them (e.g. the candy store). In this regard, the children's reconstructions are akin to the caricatures of the 'New Yorker's View of the World'. The New Yorker conflates interest and experience with actual (metric) distance: Chicago, China and California are all about the same distance from New York in this view of the world. All of these locations are relatively uninteresting to the New Yorker, and he or she simply treats them as 'away from New York'. Similarly, the young children's reconstructions conflated interest and experience with actual metric distance. The store that sold candy and toys, for example, was placed closer to the school than it should be. The children's constructions of the layout of the town should not be construed simply as reflecting distortions of otherwise abstract, metric representations. The term distortion implies a reference to another representation – a map-influenced representation. In this case, the young child's representation is fundamentally different from the map-derived model, and a comparison to this model is therefore misleading.

The second important characteristic of younger children's reconstructions is that they seem to lack knowledge of how the objects can be embedded within an overall framework. They do not seem to think that it is important to integrate the locations into a systematic

plan of the town. The younger children's reconstructions of the town thus seem very different from traditional maps. In contrast, the older children's reconstructions do seem like traditional maps. The older children maintained what Piaget called the coordinate whole, and their placements of objects reflected knowledge of the relations among the locations.

The present theoretical analysis suggests that part of the explanation of the observed results is that the children lacked a map-influenced model of space. Piaget's tasks captured important developmental differences in how children think about spatial information, particularly information that cannot be perceived in a single glance. In essence, Piaget was measuring the ability of the child to think about large-scale space in map-like terms; children's reconstructions were said to reflect an absolute conception of space if the reconstructions resembled actual maps of the town. The 5- and 6-year-olds did not possess this model of the world, and hence their reconstructions did not resemble maps. Put simply, the perspective advanced here suggests that older children's reconstructions of the town look more like actual maps because they have become familiar with the way that maps typically represent spatial information. The younger children's reconstructions may not reflect a fundamental problem in representing or manipulating the relevant spatial information as much as lack of experience with the model of the world that the maps help to create.

A similar analysis can also be applied to children's comprehension of real, geographic-scale maps. Young children can understand some of the basic functions of maps, and they can comprehend some map-related concepts such as coordinate systems (Somerville & Bryant, 1985; Bryant & Somerville, 1986; Blades & Spencer, 1989). However, the early competence that young children demonstrate is not the end of the developmental story. For example, research on children's understanding of maps and aerial photographs of real, geographic-scale spaces has revealed that even elementary school children sometimes do not grasp fully the relation between a map or photograph and the represented space (Liben & Downs, 1992, 1993; Liben, 1993, 1999). For example, consider children's responses in tasks in which they are asked to identify features on maps. Typically, the researcher points to a particular feature, such a house or road, and asks the child to identify it. Children often are able to identify a substantial percentage of the depicted objects or locations (Liben & Downs, 1989, 1991; Blades & Spencer, 1994; Blades *et al.*, 1998). For example, children usually can recognize bodies of water and large buildings. However, Liben and Downs have documented several situations in which children do not appear to

understand basic representational functions of maps. For example, one kindergartner said that a red line on a map could not represent a road because no roads are red in the world. Similarly, another kindergartner said that the representation of a road could not be a road because it was too narrow to accommodate a car. Likewise, another child correctly identified a large body of water (Lake Michigan on a small-scale map of Chicago), but then claimed to be able to see the lifeguard stand at the beach. Seeing the lifeguard stand would not be possible at the scale at which the map was drawn.

Children's errors are particularly interesting because they seem to indicate that they do not fully conceive of large-scale space in abstract terms (Liben & Downs, 1991; Liben, 1999). Children have not yet acquired a full understanding of how the maps stand for the represented spaces, and in addition they have not acquired the model of large-scale space that comes from using maps. Children often relate their personal experiences of items on maps to items that are usually found near the depicted items. For example, the child who claimed to be able to see a lifeguard stand on the small-scale map probably often encountered a lifeguard stand when he or she visited the beach. In interpreting map features, children recount their experiences of what is associated with the represented objects on the map. Thus there is a similarity between how children represent information that they acquire from direct experience navigating in the world and their naïve interpretation of geographic-scale maps. In both cases, young children interpret and recall features in terms of how they have experienced the information directly.

#### *Young children have difficulty acquiring survey knowledge*

The examples discussed thus far have involved children's construction or interpretation of map-like representations of the world. However, the map-derived model is not limited to how children interpret these external representations. Experience in using maps may also influence how children think about and mentally represent information gained from direct experience navigating in the world.

One relevant example concerns the acquisition of what is often called *survey knowledge*. Survey knowledge 'takes a static view from above the environment and locates landmarks with respect to each other' (Tversky, 1996, p. 479). An important characteristic of survey knowledge is what Levine, Jankovic and Palij (1982) have called *equiavailability*. This refers to knowledge of the multiple relations among multiple locations in a set of spatial objects, akin to the kind of knowledge represented in Figure 1.

Survey representations appear to be part of the repertoire of adults' representations of spatial information. For example, Taylor and Tversky (1992) found that adults could readily form survey-like representations of several hypothetical spaces based upon either route-like descriptions of the spaces or survey-like descriptions. Almost all adults performed well, including those who were read the route-like descriptions first and were not told in advance that they would need to draw a map of the space. Thus adults are capable of forming survey representations both from maps and from other sources of information, such as navigation and descriptions (see also Levine *et al.*, 1982; Landau, 1988; Taylor & Tversky, 1992; Tversky, 1996).

But the same cannot be said of young children. Although young children can navigate well through many spaces, they are less likely than older children and adults to form survey representations based on their direct experience of the spaces (Siegel & White, 1975; Hazen, Lockman & Pick, 1978; Cousins, Siegel & Maxwell, 1983; Herman, Shiraki & Miller, 1985; Anooshian & Kromer, 1986; Anooshian & Nelson, 1987). For example, Herman *et al.* (1985) investigated preschoolers' knowledge of the layout of their preschool. The children ranged from 3 to 5 years old. The researchers studied how children's mental representations changed as they learned more about the locations of objects both inside and outside the preschool. Several measures of children's survey knowledge of the space were taken across the school year. For example, in one task, the children were asked to point to locations that could not be seen from where they were currently standing. Most of the target locations were familiar or even well known to the children, and it was highly likely that the children would have experienced all of them in the course of their everyday navigation. However, the children had *not* experienced the *relations* among many of the locations directly. For example, the children might have traveled many times to both the water fountain and the playground but they had never been asked to think about the spatial relations between these two locations. The task of pointing to the unseen locations required that they transcend the knowledge that they had acquired through navigation in the preschool. Having a survey-like representation of the preschool probably would facilitate performance on this task. In general, children performed poorly on inference tasks. Other researchers have obtained similar findings in different kinds of environments (Hazen *et al.*, 1978; Cousins *et al.*, 1983).

How might maps influence the development of the ability to form and use survey representations of space, even when knowledge of the space is based on

navigation? Several characteristics of survey representations bear important similarities to characteristics of maps; a 'survey [representation] is analogous to a map in many ways' (Tversky, 1996, p. 479). For example, both prototypical maps and survey representations imply a representation of space that is not directly tied to the way the information has been experienced during navigation. In addition, both maps and survey representations make accessible information about relations among multiple locations, and the relations among these locations. These similarities may indicate that maps help people to think about space in survey-like ways and to form survey representations. More specifically, experience with maps could facilitate the acquisition of survey representations in two ways. First, it could give children insight into overhead perspective that is necessary for forming a survey-like representation of the environment. Second, it could give them practice in thinking about space in terms of multiple relations among multiple locations. This insight and exposure might help children to realize that information gained from navigation can also be thought of in survey-like ways. In sum, children might gain from maps the understanding *that* and *how* information can be abstracted from direct experience and integrated into a survey-like representation.

#### *Young children perform particularly poorly in large-scale spaces*

A third important developmental difference that has often been discussed in the literature concerns the effects of the size of the space in which the tasks take place. There is often an interaction between age and the size of the space; younger children (i.e. preschoolers and kindergartners) perform much worse in relatively large spaces than in smaller spaces (Pick, 1976; Herman & Siegel, 1978; Acredolo, 1981; Pick & Lockman, 1981; Weatherford, 1982). Older children are generally less affected by the size of the space.

The work of Herman and Siegel (1978) provides a particularly relevant example of the effects of these differences. These researchers asked kindergartners, second-graders and fifth-graders to learn the locations of landmarks within a model town. The model town was placed either in a small classroom or in a large gymnasium. The children first walked through the model town several times. Then, the experimenters removed the landmarks and asked the children to place them back in the correct locations. Even kindergartners placed the objects close to the correct locations when the model town was placed in the classroom. However, in the larger gymnasium, the kindergartners performed poorly. These results are particularly interesting because

they demonstrate a specific effect of the size of the space in which the task took place. The model town itself and the relative positions of the landmarks were identical in the two conditions. The only difference was the absolute size of the surrounding space.

The interaction between the effects of age and the size of the surrounding space has often been attributed to differences in the cues that are available for encoding individual locations in small-scale as opposed to large-scale spaces (Herman & Siegel, 1978; Acredolo, 1981; Huttenlocher & Newcombe, 1984). In a small-scale space, the children can rely on features of the surrounding room, such as corners and windows, to encode the locations of individual objects. In contrast, in a larger room, such as the gymnasium that Herman and Siegel used, the external framework of the room is less available. In this situation, mentally *imposing* an absolute framework or coordinate system on the locations may facilitate substantially children's memory for the locations. A mentally imposed frame of reference would allow the children to encode locations in terms of relations to other locations.

The abstract frame of reference, or a coordinate system, is precisely the kind of representational aid that may come in part from exposure to maps. Looking at maps may help children realize that there are ways of encoding spatial information that are not tied directly to specific landmarks. Both the abstract concept of space that maps entail, and the specific way in which they represent space, could help children to think about space in a way that would facilitate their performance in large-scale space.

In sum, many of the prior characterizations of the development of spatial cognition in the later preschool and early elementary school years seem to involve changes in how children think about large-scale space. Although very young children may be able to encode the locations of individual items in a small-scale space very accurately, this does not mean that they readily or spontaneously apply these skills to a large-scale space. Maps may play a critical role in helping children to think about the spaces beyond their immediate experience in absolute and survey-like terms.

## **Research evidence**

In this section, I consider the results of specific studies that support the claim that exposure to maps, or to the kinds of information that maps can provide, may facilitate children's performance on spatial tasks. In part, the evidence consists of studies that have investigated the effects of exposure to the overhead view,

regardless of the use of maps. Other studies have directly assessed the effects of using maps on children's acquisition of survey-like representations of a space.

#### *Exposure to the overhead view*

One way in which exposure to maps may facilitate the development of spatial cognition is by helping children to think about space from an oblique or overhead view. If this is true, then exposure to the overhead view might be expected to facilitate performance. The results of at least two studies are consistent with the claim that exposure to the overhead view of a spatial configuration can facilitate the development of young children's comprehension of the relations among locations.

In the first study, Rieser, Doxsey, McCarrell and Brooks (1982) investigated the effects of exposure to the overhead view on very young children's ability to navigate a detour in a simple maze. The children (ages 9–25 months) were asked to travel in the maze to find their mothers. Some of the infants were first raised to chest height to provide an overall, aerial view of the maze and of their mother. The children were then placed on the ground inside the maze. The dependent variable was whether they would go around a barrier to reach their mothers, who the infants could not see from the ground-level perspective. Exposure to the overhead view facilitated the 25-month-olds' performance. Of course, this study involved children far younger than the age at which children start to learn about maps. Nevertheless, it is noteworthy that simply exposing children to the overhead view facilitated their ability to make what is essentially a spatial inference.

Gauvain and Rogoff (1986) also demonstrated the relevance of the overhead view for acquiring survey-like representations of large-scale space. The children in this experiment were ages 6–9. They were asked to navigate a playhouse that consisted of several rooms. Half of the children were given instructions to learn the overall layout of the playhouse. These children were told to remember where all of the objects that they had seen were located. The remaining children were given route instructions; they were told to learn a specific route through the playhouse. In one room, the experimenters placed a slide from which all other rooms were visible. The older children who were asked to learn the overall layout of the playhouse spent significantly more time on top of the slide. In addition, they knew the relations among the various locations better than children who were given route instructions.

It should be noted that other research has failed to confirm that exposure to the overhead view facilitates

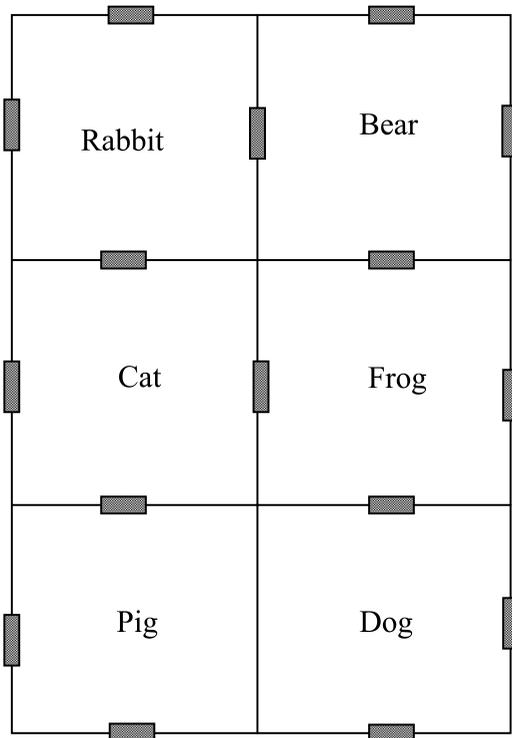
children's performance. Liben and Yekel (1996) allowed 4- and 5-year-olds to study the layout of their classrooms from a booth located above the classroom. The children were then asked to locate stickers on maps of the classroom to indicate the location of different objects. Exposure to the overhead view did not facilitate performance. Although the cause of the differences between these results and those of Rieser *et al.* (1982) and Gauvain and Rogoff (1986) is not clear, one potentially important difference concerns the tasks that children were asked to perform. In the studies (Rieser *et al.*, 1982; Gauvain & Rogoff, 1986) that have found positive effects of exposure to the overhead view, the children were asked to use the information that they gained from the overhead view as a guide to navigation. In the Liben and Yekel study, children were asked to perform tasks on maps.

#### *Consequences of exposure to maps*

There is also evidence that exposure to maps can directly facilitate young children's acquisition of a survey-like representation of a large-scale space. For example, Uttal and Wellman (1989) demonstrated that exposure to a map could aid children's acquisition of a mental representation that included multiple relations among multiple locations. Children were asked to learn the layout of a playhouse that consisted of six contiguous rooms, as shown in Figure 2. The rooms were identified by the presence of a single toy animal in each room; thus the rooms were referred to as 'the dog's room', 'the cat's room' and so forth. Half of the children, the *map group*, learned the layouts from a simple map that showed the six rooms and the doors that connected the rooms. Small photographs were attached to the corresponding locations on the map. The children were required to memorize the map before entering the playhouse.

The remaining children, the *control group*, did not use a map. Instead, they learned *what* animals could be found in the playhouse from a series of flashcards. The experimenter presented the cards, in random order, and then asked the children to recall each of the animals. This procedure was repeated until the children had learned the list of the six animals that could be found in the playhouse. Thus, the control group knew what animals they could find in the playhouse but they did not learn the spatial locations of these animals before they entered the space.

After learning either the map or the flashcards, both groups of children were asked to navigate a circuitous route through the playhouse. Before they entered each room, the children were asked to anticipate what animal



**Figure 2** The layout of the six locations used by Uttal and Wellman (1989). The shaded regions represent doors.

would be found in the room. All of the doors to the different rooms were closed, and hence the only way for children to know which animal could be found in each room was to recall what they had learned before entering the maze – either the map that showed the locations of the animals or the flashcards that gave children only the identity of the animals. The researchers assessed children’s knowledge of the layout of the playhouse by asking them to guess which animal would be found in each room. The key dependent variable was the number of animals that children could correctly identify.

Children who learned the map performed significantly better than those who learned the flashcards. Uttal and Wellman claimed that the only way children could have performed as well as they did was to form a survey-like representation of the represented space. The results of this study suggest that maps can help young children to think about space in survey-like ways. In sum, the available evidence is consistent with the claim that exposure to the unique characteristics of maps (e.g. the view from above and relations among locations) can lead to substantial improvements in performance and the acquisition of survey-like representations of the space.

## Testing the theory

The results of previous studies are consistent with the notion that exposure to maps helps children to think about space in terms of integrated, survey-like representations. However, most of these studies have been conducted in relatively small spaces, and additional evidence will be needed to support the claim that exposure to maps could facilitate the development of concepts of large-scale space. In this final section I consider how the present general theoretical claims could be tested.

Providing support for the theory will require demonstrating that exposure to maps alters how children think about the spatial relations within an environment. It will not be sufficient to demonstrate that children can learn information from maps, or even that exposure to maps helps children know *more* about a given space than they knew before. Instead, if the present hypotheses are correct, then exposure to maps should lead to a gradual, qualitative change in children’s reasoning about spatial locations. To provide evidence for such a change, I suggest that researchers *not* include all relevant locations on the maps that children see. If the present claims are correct, the exposure to maps should alter how children think about locations even if these specific locations are now shown on the map. My claim is not only that maps allow us to learn more about the world. I suggest also that maps alter how we think about spatial relations. If this is true, then the effect of exposure to a map should extend beyond simply knowing more about the particular locations that were shown on a map; the effect should extend as well to locations that were not shown on the map.

The proposed experiments would involve exposing children to maps of an area and then observing how this exposure influences their acquisition and thought about spatial information. The experiments will require a longitudinal design, but they will not require a great deal of time to complete. Many of the proposed experiments would follow a microgenetic approach, which involves investigating cognitive change intensively over a relatively short period of time (Siegler, 1996; Siegler & Stern, 1998). In the remainder of this section I discuss several possible venues for conducting these studies.

### Familiar environments

One set of studies could be conducted in an environment with which children are reasonably familiar, such as their neighborhood. Their familiarity presumably would come largely from their direct experience navigating in the environment. Several lines of research have demonstrated developmental differences in how children of

different ages represent locations within a familiar environment. Despite months or even years of exposure to the environment, younger children's mental representations are usually tied to what they have experienced directly and the routes that they have followed previously (e.g. Siegel & White, 1975; Cousins *et al.*, 1983; Herman *et al.*, 1985). Preschoolers have trouble making inferences about relations among landmarks that are not directly on routes that they have traveled. The guiding question of the proposed study would be whether exposure to a map would facilitate these kinds of judgments.

The researcher would begin by recruiting children who come from the same neighborhood because they are likely to share knowledge of the layout of this particular environment. The researcher would then assess children's knowledge of the neighborhood. These baseline assessment tasks could be similar to those used by Piaget, including a construction of maps or scale-models of the landscape. The child could also be asked to point to out-of-sight locations or to make detours in following routes. Other more sophisticated methods could also yield additional information. For example, children could be asked to rank-order the locations of landmarks in terms of distances (Kosslyn, Pick & Fariello, 1974; Newcombe & Liben, 1982). The data could then be converted to a multidimensional scaling solution to provide a map of each child's representation of the environment.

These initial measurements of children's knowledge of the environment would then be used as a baseline to assess the effects of exposing children to maps of the neighborhood. A critical question concerns the selection of landmarks to include on the map. One possibility would involve a map that showed only a few key features; several of the features that children had experienced in their daily travels would *not* be included on the map. This would allow the researcher to test whether exposure to the survey-like perspective of a map altered how children thought about the information that they had gained from direct experience. In other words, the researcher would examine not only whether the map helped children learn more about the space but also whether it helped them to think about the space in a different way.

In the map-familiarization procedure, the child would be asked to identify or describe the landmarks, following procedures similar to those of Blades *et al.* (1998) and Liben and Downs (1993). For example, the experimenter would point to the representation of the child's school and ask the child, 'Do you know what this is?' The experimenter would continue to point out landmarks on the map until the child could relate each to its referent.

After the map-familiarization phase, the experimenter and child would return to the neighborhood that was represented on the map. The experimenter would then repeat the initial assessment of the child's knowledge of the layout of the environment. The cycle could be repeated several times, probably over the course of a few weeks. If the present theoretical perspective is correct, then exposure to the maps should lead gradually to a substantial improvement in the ability to make inferences about or point to unseen locations that are not tied to specific routes that the children have experienced directly. This effect should be evident even for locations that were not shown on the map.

#### *Unfamiliar environments*

An analogous program of research could be conducted to assess how maps influence children's acquisition of information about environments with which they are initially unfamiliar. The present theoretical perspective leads to the prediction that exposure to a map should alter how children learn a new environment. Children who learn from a map, or from both direct experience and a map, should be better at inferring relations between locations. One way to approach this line of work would be to replicate the study of Herman *et al.* (1985), who investigated how children learned the layout of a preschool. However, in the proposed study, researchers would also include additional groups of children who are exposed to maps of the layout of the preschool. Specifically, one group would learn the layout by direct exposure, as in prior studies. The experimental group would augment this exposure with exposure to maps. A third, control group could be given additional exposure to particular routes, to control for the effects of added exposure that might come from the maps. Children who are exposed to the maps should be able to perform reasonably well on inference tasks that require reasoning about relations among locations that are not on the same route, whereas children who do not see the maps should perform poorly on these tasks. As suggested above, it will be useful *not* to include all of the relevant landmarks on the maps in order to demonstrate that exposure to the maps alters how children think about the spatial information.

This basic design could be applied to the learning of many other environments. Prior studies provide useful baselines regarding how children would be expected to perform without exposure to maps. The central question is whether exposure to maps helps children to augment what they learn from direct experience.

### *Virtual environments*

The previous suggestions for testing the present theory all require assessing children's knowledge of a real environment. One potential limitation of these proposals is that it is difficult to control precisely how and when children are exposed to information about locations within an environment (although the general effects of exposure to maps should nevertheless be evident). Fortunately, emerging technologies may provide convenient and relatively inexpensive ways to address some of the research questions that have been proposed above. Virtual environments can now simulate convincingly the look and feel of real environments. In addition, they allow researchers to control precisely how and when participants see specific information (Loomis, Blascovich & Beall, 1999). Therefore researchers could test directly the claim that exposure to maps alters how children learn the layout of an environment. For example, children could be exposed to a top-down view of a space and then experimenters could observe children's virtual exploration of the space. These and other questions could be addressed more directly in a virtual environment than in a real environment.

### *The development of children's map-based distortions*

Finally, researchers should also consider how children develop specific biases or false beliefs that stem from exposure to maps. I have mentioned that it is important to keep in mind that the map-influenced conception of the world is not an accurate copy (Kuipers, 1982; Liben, 1999). For example, many people have a map-derived misconception about the size of Greenland. Although these distortions are an inevitable consequence of our dependence on maps (Tversky, 1981, 1992), their existence also reinforces the central theme of this paper: we know the world beyond our immediate experience primarily through maps. Studying the development of false beliefs about specific geographic areas might reveal that children have begun to learn about the world from maps.

## Conclusions

This paper has attempted to place the development of children's understanding of maps within a larger framework that includes research on the influences of several other symbol systems on cognitive development. Exposure to maps affects how people think about spatial information. This effect is analogous to that of written text on people's conception of language or

mathematical symbols on their conception of number. The development of spatial cognition may consist in part of learning a new model of space that is tied to how information is represented on maps.

I have focused throughout on how maps might influence children's conceptions of space. However, my goal has not been to glorify maps. The changes that are brought about through learning about maps are not completely positive. As discussed above, maps create systematic biases. In addition, they reify political boundaries that may have relatively little to do with actual divisions on the ground. For example, when a person looks at a map of the former Yugoslavia, he or she can get the sense that the frontiers are rigid and stable. However, the political boundaries that are shown so clearly on maps may be much less important than the ethnic divisions that the maps do not show (see Wood, 1992). In sum, our conceptions of large-scale space are wedded to maps, for better and for worse. Perhaps the most interesting questions concern the development of this relationship.

## Acknowledgements

Portions of this work were supported by Grant R29 HD 34929 from the National Institute for Child Health and Human Development and LIS Grant 97201313 from the National Science Foundation. Portions of the paper were completed while the author was a visiting researcher at the Max Planck Institute for Human Development, Berlin. I thank Dedre Gentner for her help in developing the ideas presented in this paper and for her comments on previous versions. Thanks also to Mark Blades, Gerald Clore, Judy DeLoache, Cathryn Freid, Scott Freundsuh, William Hanks, Catrin Rode, Elwin Savelsbergh, Elsbeth Stern and Linda Uttal for their comments and suggestions.

## References

- Acredolo, L.P. (1981). Small- and large-scale spatial concepts in infancy and childhood. In L.S. Liben, A.H. Patterson & N. Newcombe (Eds), *Spatial representation and behavior across the lifespan* (pp. 63–82). New York: Academic Press.
- Allwein, G., & Barwise, J. (1996). *Logical reasoning with diagrams*. New York: Oxford University Press.
- Anooshian, L.J., & Kromer, M.K. (1986). Children's spatial knowledge of their school campus. *Developmental Psychology*, **22**, 854–860.
- Anooshian, L.J., & Nelson, S.K. (1987). Children's knowledge of directional relationships within their neighborhood. *Cognitive Development*, **2**, 113–126.

- Bence, V.M., & Presson, C.C. (1997). The spatial basis of young children's use of scale models. Paper presented at the Biennial Meeting of the Society for Research in Child Development, Washington, DC.
- Berndt, R.M., & Berndt, C.H. (1994). *The speaking land: Myth and story in aboriginal Australia*. Rochester, VT: Inner Traditions International.
- Bialystock, E. (1993). Metalinguistic awareness: the development of children's representations of language. In C. Pratt & A.F. Garton (Eds), *Systems of representation in children: Development and use* (pp. 211–233). Chichester: Wiley.
- Bialystock, E. (1995). Making concepts of print symbolic: understanding how writing represents language. *First Language*, **15**, 317–338.
- Bialystock, E., & Codd, J. (1996). Developing representations of quantity. *Canadian Journal of Behavioral Science*, **28**, 281–291.
- Blades, M., & Cooke, Z. (1994). Young children's ability to understand a model as a spatial representation. *Journal of Genetic Psychology*, **155**, 201–218.
- Blades, M., & Spencer, C. (1989). Young children's ability to use coordinate references. *Journal of Genetic Psychology*, **150**, 5–18.
- Blades, M., & Spencer, C. (1994). The development of children's ability to use spatial representations. In H.W. Reese (Ed.), *Advances in child development and behavior* (Vol. 25, pp. 157–199). San Diego, CA: Academic Press.
- Blades, M., Blaut, J., Davizeh, Z., Elguea, S., Sowden, S., Soni, D., Spencer, C., Stea, D., Surajpauli, R., & Uttal, D. (1998). A cross-cultural study of young children's mapping abilities. *Transactions of the Institute of British Geographers*, **23**, 269–277.
- Blaut, J.M. (1991). Natural mapping. *Transactions of the Institute of British Geographers*, **16**, 55–74.
- Bremner, J.G. (1993). Spatial representation in infancy and early childhood. In C. Pratt & A.F. Garton (Eds), *Systems of representation in children* (pp. 211–234). Chichester: Wiley.
- Brotton, J. (1998). *Trading territories: Mapping the early modern world*. Ithaca, NY: Cornell University Press.
- Bryant, P.E., & Somerville, S.C. (1986). The spatial demands of graphs. *British Journal of Developmental Psychology*, **77**, 187–197.
- Bushnell, E.W., McKenzie, B.E., Lawrence, D.A., & Connell, S. (1995). The spatial coding strategies of one-year-old infants in a locomotor search task. *Child Development*, **66**, 937–958.
- Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MA: MIT/Bradford Books.
- Cassirer, E. (1944). *An essay on man: An introduction to the philosophy of human culture*. New Haven, CT: Yale University Press.
- Cassirer, E., Mannheim, R., & Hendel, C.W. (1965). *Philosophy of symbolic forms: The phenomenology of knowledge*. New Haven, CT: Yale University Press.
- Chatwin, B. (1987). *The songlines*. New York: Viking.
- Cousins, J.H., Siegel, A.W., & Maxwell, S.E. (1983). Way finding and cognitive mapping in large-scale environments: a test of a developmental model. *Journal of Experimental Child Psychology*, **35**, 1–20.
- Crosby, A. (1998). *The quantification of reality: Quantification and Western society*. New York: Cambridge University Press.
- DeLoache, J.S. (1987). Rapid change in the symbolic functioning of very young children. *Science*, **238**, 1556–1557.
- DeLoache, J.S. (1989). Young children's understanding of the correspondence between a scale model and a large space. *Cognitive Development*, **4**, 121–139.
- DeLoache, J.S. (1991). Symbolic functioning in very young children: understanding of pictures and models. *Child Development*, **62**, 736–752.
- DeLoache, J.S. (1995). Early understanding and use of symbols: the model model. *Current Directions in Psychological Science*, **4**, 109–113.
- Dent, B.D. (1996). *Cartography*. Dubuque, IA: William C. Brown.
- Dow, G.A., & Pick, H.L. (1992). Young children's use of models and photographs as spatial representations. *Cognitive Development*, **7**, 351–363.
- Downs, R.M. (1981). Maps and mappings as metaphors for spatial representation. In L.S. Liben, A.H. Patterson & N. Newcombe (Eds), *Spatial representation and behavior across the lifespan* (pp. 143–166). New York: Academic Press.
- Downs, R.M., & Liben, L.S. (1993). Mediating the environment: communicating, appropriating, and developing graphic representations of space. In R.H. Wozniak & K.W. Fischer (Eds), *Development in context: Acting and thinking in specific environments* (pp. 155–181). Hillsdale, NJ: Erlbaum.
- Eliot, J. (1987). *Models of psychological space: Psychometric, developmental, and experimental approaches*. New York: Springer.
- Gattis, M., & Holyoak, K. (1996). Mapping conceptual to spatial relations in visual reasoning. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **22**, 231–239.
- Gauvain, M. (1993). The development of spatial thinking in everyday activity. *Developmental Review*, **13**, 92–121.
- Gauvain, M. (1995). Thinking in niches: sociocultural influences on cognitive development. *Human Development*, **38**, 25–45.
- Gauvain, M., & Rogoff, B. (1986). Influence of the goal on children's exploration and memory of large-scale space. *Developmental Psychology*, **22**, 72–77.
- Gell, A. (1983). How to read a map: remarks on the practical logic of navigation. *Man*, **20**, 271–286.
- Gentner, D., & Ratterman, M.J. (1991). Language and the career of similarity. In S.A. Gelman & J.P. Byrnes (Eds), *Perspectives on language and thought: Interrelations in development* (pp. 225–277). New York: Cambridge University Press.
- Gladwin, T. (1970). *East is a big bird: Navigation and logic on Puluwat atoll*. Cambridge, MA: Harvard University Press.
- Hazen, N.L., Lockman, J.J., & Pick, H.L. (1978). The

- development of children's representations of large-scale environments. *Child Development*, **49**, 623–636.
- Herman, J.F., & Siegel, A.W. (1978). The development of cognitive mapping of the large-scale environment. *Journal of Experimental Child Psychology*, **26**, 389–406.
- Herman, J.F., Shiraki, J.H., & Miller, B.S. (1985). Young children's ability to infer spatial relationships: evidence from a large, familiar environment. *Child Development*, **56**, 1195–1203.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.
- Huttenlocher, J.E., & Newcombe, N. (1984). The child's representation of information about location. In C. Sophian (Ed.), *Origins of cognitive skills* (pp. 81–112). Hillsdale, NJ: Erlbaum.
- Huttenlocher, J.E., Newcombe, N., & Sandberg, E.H. (1994). The coding of spatial location in young children. *Cognitive Psychology*, **27**, 115–148.
- Jammer, M. (1993). *Concepts of space: The history of theories in space in physics* (3rd edn). New York: Dover.
- Karmiloff-Smith, A. (1979). Micro- and macrodevelopmental changes in language acquisition and other representational systems. *Cognitive Science*, **3**, 91–117.
- Karmiloff-Smith, A. (1990). Constraints on representational change: evidence from children's drawing. *Cognition*, **34**, 57–83.
- Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science*. Cambridge, MA: MIT Press.
- Kosslyn, S.M., Pick, H.L., & Fariello, G.R. (1974). Cognitive maps in children and men. *Child Development*, **45**, 707–716.
- Kuipers, B. (1982). The 'map-in-the-head' metaphor. *Environment and Behavior*, **14**, 202–220.
- Landau, B. (1986). Early map use as an unlearned activity. *Cognition*, **22**, 201–223.
- Landau, B. (1988). The construction and use of spatial knowledge in blind and sighted children. In J. Stiles-Davis, M. Kritchewsky, & U. Bellugi (Eds), *Spatial cognition: Brain bases and development* (pp. 343–371). Hillsdale, NJ: Erlbaum.
- Larkin, J.H., & Simon, H.A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science*, **11**, 65–100.
- Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life*. Cambridge: Cambridge University Press.
- Lee, K., & Karmiloff-Smith, A. (1996). The development of external symbol systems: the child as a notator. In R. Gelman & T.K.-F. Au (Eds), *Perceptual and cognitive development: Handbook of perception and cognition* (2nd edn, pp. 185–211). San Diego, CA: Academic Press.
- Levine, M.S., Jankovic, I.N., & Palij, M. (1982). Principles of spatial problem solving. *Journal of Experimental Psychology: General*, **111**, 157–175.
- Lewis, D. (1972). *We the navigators: The ancient art of landfinding in the pacific*. Honolulu, HI: University of Hawaii Press.
- Lewis, D. (1976). Observations on route finding and spatial orientation among the aboriginal peoples of the western desert region of central Australia. *Oceania*, **46**, 249–282.
- Liben, L.S. (1993). Environmental cognition through direct and representational experiences: a life-span perspective. In T. Gaerling & G.W. Evans (Eds), *Environment, cognition, and action: An integrated approach* (pp. 245–276). New York: Oxford University Press.
- Liben, L.S. (1999). Developing an understanding of external spatial representations. In I.E. Sigel (Ed.), *Development of mental representation: Theories and applications* (pp. 297–321). Mahwah, NJ: Erlbaum.
- Liben, L.S. (in press). Thinking through maps. In M. Gattis (Ed.), *Spatial schemas in abstract thought*. Cambridge, MA: MIT Press.
- Liben, L.S., & Downs, R. (1989). Understanding maps as symbols: the development of map concepts in children. In H.W. Reese (Ed.), *Advances in child development and behavior* (Vol. 22, pp. 146–201). New York: Academic Press.
- Liben, L.S. & Downs, R.M. (1991). The role of graphic representations in understanding the world. In R.M. Downs, L.S. Liben & D.S. Palermo (Eds), *Visions of aesthetics, the environment, and development: The legacy of Joachim F. Wohlwill* (pp. 139–180). Hillsdale, NJ: Erlbaum.
- Liben, L.S., & Downs, R.M. (1992). Developing an understanding of graphic representations in children and adults: the case of GEO-graphics. *Cognitive Development*, **7**, 331–349.
- Liben, L.S., & Downs, R.M. (1993). Understanding person–space–map relations: Cartographic and developmental perspectives. *Developmental Psychology*, **29**, 739–752.
- Liben, L.S., & Yekel, C. (1996). Preschoolers' understanding of plan and oblique maps: the role of geometric and representational correspondence. *Child Development*, **67**, 2780–2796.
- Loomis, J.M., Blascovich, J.J., & Beall, A.C. (1999). Immersive virtual environments as a basic research tool in psychology. *Behavior Research Methods, Instruments, and Computers*, **31**, 557–564.
- Luria, A. (1976). *Cognitive development: Its cultural and social foundations*. Cambridge, MA: Harvard University Press.
- McLuhan, M. (1964). *The Gutenberg galaxy: The making of typographic man*. Toronto: University of Toronto Press.
- McNamara, T.P. (1986). Hierarchies in cognitive maps. *Cognitive Psychology*, **18**, 87–121.
- Miller, K.F. (1989). Measurement as a tool for thought: the role of measuring procedures in children's understanding of quantitative invariance. *Developmental Psychology*, **25**, 589–600.
- Miller, K.F., & Paredes, D.R. (1996). On the shoulders of giants: cultural tools and mathematical development. In R.J. Sternberg & T. Ben-Zeev (Eds), *The nature of mathematical thinking* (pp. 83–117). Mahwah, NJ: Erlbaum.
- Miller, K.F., & Stigler, J.W. (1991). Meanings of skill: effects of abacus expertise on number representation. *Cognition and Instruction*, **8**, 29–67.

- Montello, D.R. (1993). Scale and multiple psychologies of space. In A.U. Frank & I. Campari (Eds), *Spatial information theory: A theoretical basis for GIS* (pp. 312–321). Berlin: Springer.
- Montello, D.R., & Golledge, R.G. (1999). *Scale and detail in the cognition of geographic information*. Report of Specialist Meeting of Project Varenus held 14–16 May 1998 in Santa Barbara, CA. University of California at Santa Barbara, <http://www.ncgia.org>.
- Newcombe, N., & Huttenlocher, J. (2000). *Making space: Taking cognitive development one domain at a time*. Cambridge, MA: MIT Press.
- Newcombe, N., & Liben, L.S. (1982). Barrier effects in the cognitive maps of children and adults. *Journal of Experimental Child Psychology*, **34**, 46–58.
- Newcombe, N., Huttenlocher, J., & Learmonth, A. (in press). Spatial memory in 5-month-old infants. *Infant Behavior and Development*.
- Olson, D.R. (1994). *The world on paper: The conceptual and cognitive implications of writing and reading*. Cambridge: Cambridge University Press.
- Olson, D.R. (1996). Literate mentalities: literacy, consciousness of language, and modes of thought. In D.R. Olson & N. Torrance (Eds), *Modes of thought: Explorations in culture and cognition* (pp. 141–151). New York: Cambridge University Press.
- Ong, W.J. (1982). *Orality and literacy: The technologizing of the word*. London: Methuen.
- Piaget, J., & Inhelder, B. (1956). *The child's conception of space*. New York: Norton.
- Piaget, J., Inhelder, B., & Szeminska, A. (1960). *The child's conception of geometry*. New York: Norton.
- Pick, H.L., Jr (1976). Transactional-constructivist approach to environmental knowing: a commentary. In G.T. Moore & R.G. Golledge (Eds), *Environmental knowing* (pp. 185–188). Stroudsburg, PA: Dowden, Hutchinson & Ross.
- Pick, H.L., & Lockman, J.J. (1981). From frames of reference to spatial representations. In L.S. Liben, A.H. Patterson & N. Newcombe (Eds), *Spatial representation and behavior across the lifespan* (pp. 39–62). New York: Academic Press.
- Presson, C.C. (1982). The development of map-reading skills. *Child Development*, **53**, 196–199.
- Presson, C.C., Hazelrigg, M.D., & DeLange, N. (1987). Orientation specificity in spatial memory: what makes a path different from a map of the path? *Journal of Experimental Psychology: Learning, Memory and Cognition*, **15**, 887–897.
- Rieser, J.J., Doxsey, P.A., McCarrell, N.S., & Brooks, P.H. (1982). Wayfinding and toddlers' use of information from an aerial view of a maze. *Developmental Psychology*, **18**, 714–720.
- Shelton, A.L., & McNamara, T.P. (1997). Multiple views of spatial memory. *Psychonomic Bulletin and Review*, **4**, 102–106.
- Shin, S.J. (1994). *The logical status of diagrams*. Cambridge: Cambridge University Press.
- Siegel, A.W., & White, S.H. (1975). The development of spatial representations of large-scale environments. In H.W. Reese (Ed.), *Advances in child development and behavior* (Vol. 10, pp. 9–55). New York: Academic Press.
- Siegler, R.S. (1996). *Emerging minds: The process of change in children's thinking*. New York: Oxford University Press.
- Siegler, R.S., & Stern, E. (1998). Conscious and unconscious discoveries: a microgenetic analysis. *Journal of Experimental Psychology: General*, **127**, 377–397.
- Somerville, S.C., & Bryant, P.E. (1985). Young children's use of spatial coordinates. *Child Development*, **56**, 604–613.
- Spencer, C., Blades, M., & Morsley, K. (1989). *The child in the physical environment: The development of spatial knowledge and cognition*. Chichester: Wiley.
- Staub, F.C., & Stern, E. (1997). Abstract reasoning with mathematical constructs. *International Journal of Educational Research*, **27**, 63–75.
- Stern, E. (1993). What makes certain arithmetic word problems involving comparison of sets so difficult for children? *Journal of Educational Psychology*, **85**, 7–23.
- Stigler, J.W. (1984). 'Mental abacus': the effect of abacus training on Chinese children's mental calculation. *Cognitive Psychology*, **16**, 145–176.
- Stigler, J.W., Chalip, L., & Miller, K.F. (1986). Consequences of skill: the case of abacus training in Taiwan. *American Journal of Education*, **94**, 447–479.
- Taylor, H.A., & Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. *Journal of Memory and Language*, **31**, 261–292.
- Thorndyke, P.W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*, **14**, 560–589.
- Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology*, **13**, 407–433.
- Tversky, B. (1992). Distortions in cognitive maps. *Geoforum*, **23**, 131–138.
- Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. In A.U. Frank & I. Campari (Eds), *Spatial information theory: A theoretical basis for GIS* (pp. 14–24). Berlin: Springer.
- Tversky, B. (1996). Spatial perspective in descriptions. In P. Bloom, M.A. Peterson, L. Nadel & M.F. Garrett (Eds), *Language, speech, and communication* (pp. 463–491). Cambridge, MA: MIT Press/Bradford Books.
- Tversky, B. (1998). Three dimensions of spatial cognition. In M.A. Conway, S.E. Gathercole & C. Cornoldi (Eds), *Theories of memory II* (pp. 259–275). Hove, UK: Psychological Press.
- Uttal, D.H. (1994). Children's and adults' reconstruction and scaling of spatial configurations. *British Journal of Developmental Psychology*, **12**, 259–275.
- Uttal, D.H. (1996). Angles and distances: children's and adults' reconstruction and scaling of spatial configurations. *Child Development*, **67**, 2763–2779.
- Uttal, D.H., & Gentner, D. (1995). Maps are like analogies. Paper presented at the annual meetings of the Association of American Geographers, Charlotte, NC.
- Uttal, D.H., & Wellman, H.M. (1989). Children's mental representation of spatial information acquired from maps. *Developmental Psychology*, **25**, 128–138.

- Vosniadou, S., & Brewer, W. (1992). Mental models of the earth: a study of conceptual change in childhood. *Cognitive Psychology*, **24**, 535–585.
- Vygotsky, L.S. (1962). *Thought and language*. Cambridge, MA: MIT Press.
- Vygotsky, L.S. (1978). *Mind in society*. Cambridge, MA: MIT Press.
- Weatherford, D.L. (1982). Spatial cognition as a function of size and scale of the environment. *New Directions for Child Development*, **15**, 5–18.
- Wellman, H.M., & Miller, K.F. (1986). Thinking about nothing: development of concepts of zero. *British Journal of Developmental Psychology*, **4**, 31–42.
- Wilford, J.N. (1981). *The mapmakers*. New York: Knopf.
- Wood, D. (1992). *The power of maps*. New York: Guilford Press.

Received: 26 August 1998

Accepted: 15 December 1999