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The Development of Children's Understanding of Maps and Models: A Prospective Cognition Perspective

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This article takes a prospective cognition perspective in reviewing research on the development of children's understanding of spatial symbols, such as scale models and maps. We suggest that using spatial symbols requires that children think about where an object will be found rather than where they last saw it. In addition, we suggest that as children's knowledge of maps grows, they begin to think about large-scale space through the mediated perspective that maps provide.

Maps allow people to see and to think about multiple relations among locations, as well as spaces that are much larger than can be directly perceived. Learning about the world through maps is a good example of what Tomasello (1999) called the *cultural ratchet* effect; each generation can rely on information from prior generations rather than having to learn or discover it on their own. Thus, cultures share views of space through maps, and the development of the cognition of large-scale space consists in part of learning to think about the world through maps.

Keywords: prospective cognition; symbolic development; map comprehension; spatial relations; cultural ratchet

Prospective cognition is the idea that the brain and mind evolved to make predictions. As Clark (2013) suggests, perhaps the fundamental purpose of the brain is to predict. Because the future is uncertain, accurate predictions will give us some opportunity to plan, to avoid danger, and to seek better outcomes if we anticipate that they can be found. For these reasons, humans and other species developed mechanisms for keeping track of past observations and using the information to make estimates about the future. For example, the tendency of even young children to use Bayesian estimates when interpreting or predicting events may reflect the evolutionary development of strategies to maximize the accuracy of prospective cognition (e.g., Gopnik & Tenenbaum, 2007).

Although some aspects of prospective cognition are common to many species, humans also possess unique advantages. Culture, and the symbols that culture creates, allows us to

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think about the future at time frames that far exceed what we ever envision or predict based on direct observation alone. Only humans, for example, systematically engage in urban planning or imagine alternate (e.g., utopian or dystopian) futures. Thus, prospective cognition must consider the role of culture and symbols in expanding the scale and content of future-oriented thinking.

Our perspective on the role of culture and symbols in prospective cognition is guided by the theoretical work of Tomasello and colleagues (Tennie, Call, & Tomasello, 2009; Tomasello, 1999). They coined the term *cultural ratchet* to describe the influences of culture and symbols on the acquisition of knowledge. Symbols allow people to share discoveries across generations rather than starting afresh and having to reinvent or rediscover the information. Tomasello and colleagues suggest that this cultural transmission across generations is one of the defining characteristics of human cognition.

In this article, we take a prospective cognition perspective on the development of children's understanding and use of maps and models and on the cognitive consequences of these developments. We argue that the prospective cognition perspective sheds important new light on these issues for two reasons. First, thinking of very young children's understanding of maps and models from a prospective cognition perspective helps us to more fully understand their success and failure in prior research. We briefly consider research on the early development of children's understanding of scale models from this perspective.

Second, considering the cultural aspects of prospective cognition also helps us to understand the cognitive *consequences* of using and understanding maps and models. Maps facilitate thinking about travel at scales of both time and space that far exceed the limits of our own perception and navigation. Much of what we know about the world is, in fact, mediated by the representations (most notably but not exclusively maps) that we use to communicate information; much of what we know and think about the world comes from maps and not from direct experience. For example, although pictures of the earth as viewed from space have become commonplace, it is easy to forget that no human had actually seen the earth from space until the beginning of the space programs in the United States of America and the Soviet Union in the late 1950s. Moreover, although every schoolchild sees many maps of the United States, very few people will actually see the entire layout of the United States. Thus, much of what we know about the world, particularly at larger scales, comes not from our direct experience but culturally created representations of the world.

An important developmental corollary of our perspective is that learning to think about the world through the mediated view of maps is an important aspect of the development of spatial cognition (e.g., Liben & Downs, 1989, 1991, 1993; Liben, Kastens, & Stevenson, 2002; Uttal, 2000, 2005). Thus, like other symbols (e.g., spoken and written text), maps are cultural tools that allow us to learn about the world from others and thus greatly expand the range of human knowledge and thought (Olson, 1994). We argue here that coming to view and to think about the world through the mediated perspective of maps is an important aspect of the development of spatial cognition.

In the remainder of this article, we illustrate our theoretical perspective by considering children's performance in three tasks: (a) the early development of understanding of the symbolic relation between models and their referent spaces, (b) young children's acquisition of spatial information from maps of small-scale spaces, and (c) the development of children's conception of large-scale spaces.

THE EARLY DEVELOPMENT OF CHILDREN'S UNDERSTANDING OF THE SYMBOLIC PROPERTIES OF SCALE MODELS

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Adults, for the most part, understand the nature of symbols that communicate important information about the past, present, and future and can use them for their intended purpose. For example, adults readily appreciate pictures as representing a past event, they understand that a map can help them locate their current position, and they obey stop signs which notify them of an impending stopping action. In contrast, children must learn to appreciate and appropriately use the symbols of their culture. This section will explore the very beginnings of children's appreciation of spatial symbols from a perspective that emphasizes the representation and communication of prospective information.

DeLoache (1987) have conducted extensive research on the emergence of children's understanding of spatial symbols. In a typical task, children are asked to use a small-scale replica of a room to find a hidden toy in the larger version of the room. The task has four main steps. First, an experimenter hides a toy in the room while the child waits outside. Second, the experimenter invites the child to watch as he or she hides a smaller version of the toy in a small-scale replica model of the room. Third, the child searches for the larger version of the hidden toy in the actual room. Fourth, the child returns to the model and retrieves the toy where it was originally hidden in the model. The search in the room measures the child's use of the model as a symbol for the room, whereas the search in the model verifies that the child remembered where the toy was originally hidden in the model.

DeLoache's (1987) original experiment revealed a dramatic developmental shift in symbolic understanding. The 3-year-olds performed very well, retrieving the toy in the room on 75% of their first searches. In contrast, the 2.5-year-olds retrieved the toy on only 25% of their first attempts. The large developmental difference was not because of the younger children forgetting where the toy was hidden in the model. Both 2.5- and 3-year-olds could locate the hidden toy where it was originally hidden in the model, retrieving the miniature toy on 80% of their searches. The children remembered where the toy was hidden, but only the older children understood the correspondence between the model and the room—that the model was a symbol for the room and could be used to predict the larger toy's hiding location.

What develops from 2.5 to 3 years of age that helps children succeed on the model-room task? DeLoache (1996) argues that children's performance on the model-room task depends on the child's understanding of *dual representation*. All symbols are simultaneously objects in their own right and representations of something else. To succeed in the model-room task, children must focus less on the model as an object and more on what it represents: the room.

As evidence for this hypothesis, DeLoache, Miller, and Rosengren (1997) showed that reducing or eliminating the need for dual representation greatly facilitates young children's performance. Children were lead to believe that the experimenter had a magical machine that could make the room shrink into the model or make the model grow into the room. This clever experimental manipulation raised the performance of 2.5-year-olds from approximately 25% to approximately 75% correct searches. Convincing children that the room and the model were the same object eliminated the need for dual representation.

We believe that taking a prospective cognition perspective sheds important new light on children's performance in the model-room task and on the nature of dual representation. To succeed on the task, children must think about where the toy *was* hidden in the model to find where the toy *will be* hidden in the room. When young children search for a missing object, they typically do so based on past experience; they go to where they have seen the toy recently. But to succeed in the model-room task, children need a very different construal: They have to put aside knowledge of where the toy was last seen in the room and instead use the model to think about where the toy will be found in the room. Therefore, children's poor performance on the task reflects not only their difficulty appreciating the dual nature of the model but also their difficulty appreciating and using a symbol that informs about the future.

Children's errors in the model-room task are consistent with this prospective cognition interpretation. When children fail to find the toy, they often commit *perseverative errors*; they continue to search where they last saw the toy in the room on a previous trial and ignore the information about where the miniature toy was in the model (see Zelazo, Reznick, & Spinazzola, 1998). Put another way, children rely heavily on past information (where they last saw the toy) and either do not understand or do not use information from the model, which specifies where the toy will be when they enter the room and search (O'Sullivan, Mitchell, & Daehler, 2001; Sharon & DeLoache, 2003).

Representing a future event is especially difficult for young children if they do not experience the event themselves. Ganea and Harris (2010) had 2- and 2.5-year-old children watch as the experimenter hid a toy in the room and left the room. The children then were asked to return to the room and retrieve the toy. On some trials, the experimenter told the children that someone had moved the toy to a different hiding location. The central research question was whether children would rely (correctly) on the information that the experimenter provided or (incorrectly) on where they had last seen the toy in the room. There were 12 of the 16 older children who relied on the updated information from the experimenter and found the toy on their first search, but only 4 of the 20 younger children did so. Moreover, 87% of the children made perseverative errors by searching in the location where the toy was hidden before it was switched. In a different condition where children directly observed the object's hiding location being switched by watching through a window, both the 2- and the 2.5-year-olds searched in the correct location. Without directly viewing where the object was hidden, the younger children made perseverative errors that suggest they did not update their knowledge about the future event.

Thus, we see that children's heavy reliance on past information limits their prediction of future events, especially when the child must use a symbol to make future predictions. This observation leads to an interesting prediction: Very young children's use of symbols might be increased if the need to think about competing information from past experience was reduced or eliminated. The work of Suddendorf (2003) confirmed this prediction. He found that even 2-year-olds can use a picture to predict a future hiding location (i.e., a picture-room task) when hiding and searching trials occur in different rooms with different hiding locations. Therefore, prior hiding locations cannot interfere with new representations of where the object will be on subsequent trials. Children were correct on 53% of their searches, more than double the typical level of 25% observed in prior studies in which children searched for each toy in a different location in the same room and thus had to deal with information from prior trials. This research highlights that the problem for young children in the traditional model-room task is not only the need to use a symbol. The need to discount the strong pull of past information (prior search locations), and instead focus on where the toy *will* be, also contributes to the challenge, and eliminating this challenge makes it much easier for children to use the model as a symbol (Suddendorf, 2003).

In summary, the prospective cognition perspective helps us to reinterpret and be more specific about the meaning of dual representation. To succeed on the model-room task,

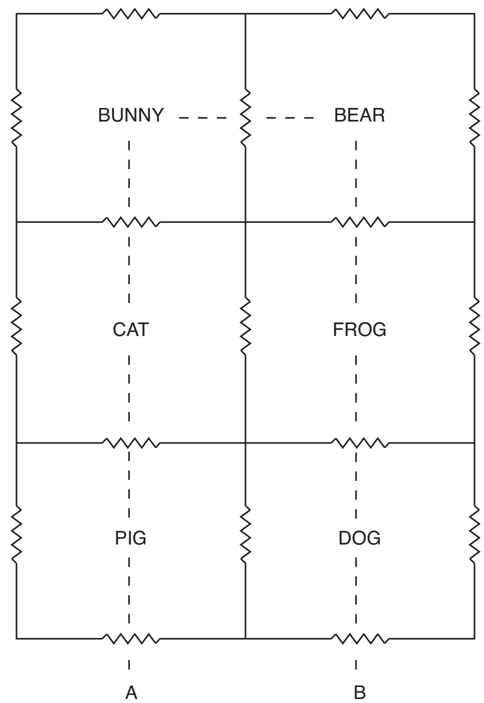

FIGURE 1. Layout of playhouse used in Uttal and Wellman (1989). The map was similar except there were no dotted lines and photographs of animals were used instead of written names.

to anticipate the locations of animals that were not on the route. For example, the experimenter pointed to the door that separated the cat's room from the frog's room (see Figure 1) and asked the child to identify which animal "lived" behind the door. These off-route judgments were important for investigating how the children had mentally represented the spatial information.

The results revealed a strong advantage for the map group, particularly on the initial trials through the playhouse. The map group answered approximately 66% of the questions about the identity of the animal in the room correctly on their first trip through the playhouse, whereas the control group answered only approximately 33%. The control group eventually caught up, but the extra time that they took shows the specific advantage of using a map. Moreover, the map allowed the children to make inferences about relations among the rooms that they never experienced while navigating in the space, giving them an advantage on their first trip. Therefore, this knowledge could *only* be learned from the map. The children in the map group represented the relations among the multiple locations, and their knowledge was not tied to any particular route or landmark. Information about the multiple relations among multiple locations is precisely the kind of advantage that maps convey, and this line of research illustrates the beginning of the ability of young children to take advantage of this feature of maps. Thus, by age 4 years, children can begin to take advantage of the unique properties of maps and learn about the world in a way that differs from how they would typically experience spatial information during navigation.

This and similar research highlights the beginning of the ability to gain from maps a perspective and information that is more challenging to acquire from direct experience. This is perhaps the first example of the beginning of the culture ratchet through which maps begin to facilitate the development of spatial cognition. In the next section, we turn to a further development—children's understanding of maps of large-scale space.

Understanding Maps of Large-Scale Space

The final set of research concerns the development of children's conceptions of large-scale space and the role of maps in understanding these spaces. This discussion leads us to consider in detail the cultural ratchet effect of maps on spatial thinking. By large-scale space, we mean spaces that are too large to perceive in a single glance. In many cases, this definition includes geographic-scale spaces—entire cities, counties, countries, and continents. This kind of work is particularly important because most psychological research on the cognition of space focuses on small-scale spaces, often small rooms or even tabletops. Geographers (e.g., Montello, 1993) have long-argued that the perception and cognition of spaces of varied sizes is fundamentally different. For example, whereas small-scale spaces can be experienced in a single glance, large- or geographic-scale spaces can only be perceived in their entirety through maps. Thus, if we are to include large-scale spaces in the study of spatial cognition, then we will also have to include research on the study of the acquisition of spatial information from maps. As we argue here, the emergence of concepts of large-scale space are intimately connected to the development of children's understanding of maps.

Liben and Downs (1989, 1991, 1993) have conducted several lines of research investigating children's interpretation of symbols on large-scale maps or aerial photographs. In one study, children were asked to look at a map or aerial photograph of Chicago. The experimenter pointed to various symbols on the map and asked the child to interpret them. For example, the experimenter pointed to the representation of Lake Michigan, and most children had little trouble recognizing that it was water (although none said it was Lake Michigan). But children's success seemed to be limited to very familiar representations or those that were icons of what they represented—water typically is blue, both on the map and in the world. Children had much more difficulty when their answers could not be derived based on physical similarity or appearance alone. For example, one child claimed to see fish in the blue area that represented Lake Michigan even though fish could not be seen at the scale of the map. Likewise, another child said that a red line on a map (that represented an interstate highway) could not represent a road because no roads are red in the world. Similarly, another child said the line could not represent a road because the line was too narrow to fit a car.

Why do children find the interpretation of the large-scale maps so difficult, particularly when they are successful in the laboratory tasks several years earlier? Often, the difficulty has been described in terms of limited spatial or representational skills. The logic of these studies seems to be that children understand the spaces that the maps represent but fail to understand how the map represents the space. Thus, the task is fundamentally one about reading maps, and young children do not yet understand the representational properties of these large-scale maps.

However, the prospective cognition perspective leads us to a different understanding of the kinds of errors that children make when interpreting large-scale maps. We do not disagree that children do not fully appreciate that the map is a representation of the space that it represents. But there is a second problem: Children do not really understand the space that the maps represent either. The map presents a view of the world that differs dramatically from what the typical child has experienced navigating in their world. Modern maps are cultural tools for portraying information about space, particularly large-scale space, and part of the development of spatial cognition consists of learning to think about space through the very different perspective that maps can provide. Our perspective on the influences of maps on spatial cognition and its development is consistent with a substantial amount of work on the influences of symbols and technologies on human thought and communication (e.g., Dehaene, 1997; Hutchins, 1995; Norman, 1993; Olson, 1994).

As an example, consider the map shown in Figure 2. Most readers will recognize it immediately as a map of Chicago. But it is important to remember that very few, if any, humans have ever actually seen this view of Chicago. The map looks nothing at all like the Chicago that a young elementary school child is likely to have encountered in everyday life. To an adult, the map is as much a valid view of Chicago as a photograph of the John Hancock building or Lake Michigan would be. Despite this belief, the maps differ from direct experience in many ways. The first is the sheer amount of information that can be communicated. Maps depict spatial information and thus allow a person to think about many more geographic-scale locations

FIGURE 2. Map of Chicago.

than can be experienced directly. But it is not simply the sheer amount of information that matters; the maps also give us a relational view of the world, allowing us to think about and to communicate the kind of information that is specifically difficult to communicate in words (see Uttal, Fisher, & Taylor, 2006). In addition, maps present a view of the world that is more abstract than the view we gain from navigating. When we look at a map, we can think and communicate information about the space itself; this information need not be tied to any particular goal or travel experience. Maps thus allow us to plan and to think about travel, regardless of immediate goals.

From a prospective cognition perspective, we are suggesting that adults internalize the model of the world that maps provide, leading to mental models of large-scale space that allow people to communicate about spaces, or spatial relations, that are far beyond the direct experience of any single person. The long-term, cumulative effect of viewing the world in this way is to think about the world as if it were laid out in front of us, rather than, for example, a series of interconnected paths or routes. The view of the world from maps becomes an internal or mental model that affects how we think and communicate about large-scale space. We call the cumulative consequences of thinking of the world from the perspective of maps the *map-mediated* view of the world. Space becomes something that we can think about, talk about, carve up, purchase, and own. In summary, we suggest that the cultural ratchet effect of spatial symbols has led adults in modern, western societies to think about the world as if they were looking at a map—even when maps are not present. The use of maps, and the cognitive consequences of map use, leaves an indelible impression on our conceptions of large-scale space.

Historical and Developmental Differences. This conception of the influences of analysis has two important implications that we consider in the next section. Because adults' conceptions of large-scale space are culturally mediated, then we may find cultural, historical, and developmental differences in how people think about large-scale space.

One well-documented historical change in conceptions of maps and of large-scale space happened in Tudor England, from approximately 1500 to 1600. In Harvey's (1993) words, "In the England of 1500 maps were little understood or used. By 1600 they were familiar objects of everyday life." Harvey labels these changes a "cartographic revolution" (1993, p.18). In the span of about 100 years, people's concepts of maps, and of the spaces that maps represented, changed dramatically. For example, before the cartographic revolution, people's conceptions of land ownership were often based on local geographic features or on uses of the land. After the revolution, surveying and the inclusion of plots in land transactions became standard. Shakespeare's King Lear asks for a map when he is dividing up his kingdom among his daughters; Harvey claims that audiences 100 years before would not have understood why the King would want or need a map to make this division.

What happened during these 100 years that changed so fundamentally how people thought about large-scale space? It is important to note that this cognitive revolution was *not* the invention of maps. Maps were known to some for centuries, if not millennia, before the British cartographic revolution (Wilford, 2001). For example, Ptolemy's (1991) great atlases of the world were prepared approximately 1,500 years before the British cartographic revolution, but these representations of the world for the most part were lost during the Middle Ages and were certainly not available to a large percentage of the population before the advent of readily available maps in print.

Instead, the fundamental cognitive change that led to the cartographic revolution was the acquisition of the map-mediated view of the world and the consequences of that acquisition for trade and communication. The rediscovery of the power of maps to represent large-scale spaces, and the eventual cultural adoption of the map-mediated view of the world, is a very good example of the cultural ratchet effect. People began to use maps to present to others a prospective view of the world, one that was not immediately tied to a particular journey but rather presented the possibilities of infinite journeys, and as areas that could be explored, conquered, and owned. Subsequent generations then did not have to rediscover the map-mediated view of the world on their own but could instead rely on the maps, discussions, and instructions of the previous generations. Thus, at least in England, we can pinpoint historically the cognitive, cartographic, and conceptual changes that were associated with the emergence of the map-mediated view of the world.

Ong (1982) summed up well the changes in conceptions and beliefs that were associated with the emergence of maps and the map-mediated view of the world.

> 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 the eyes, as in a modern printed atlas, a vast surface or assemblage of surfaces (vision presents surfaces) ready to be 'explored' (p. 73).

Development. We are now ready to return to the results that motivated this discussion: Why do young children have difficulty interpreting maps of large-scale places when they seem to do much better with maps that represent smaller spaces? From our viewpoint, the child has not yet acquired the culturally mediated view of the world that maps can provide. The child is asked to interpret a map of a space that can only be known through the perspective of the map itself. The experimenter assumes the child shares the map-mediated view of the world, but he or she does not. The problem then is not simply that the child does not understand maps but rather that he does not understand spaces at the scales and perspectives that maps can provide. Then, when asked to interpret features on maps, the best the child can do is to rely on physical similarities, such as the blue color of water, because identifying these correspondences does not require an appreciation of the map-mediated view of the world.

The development of large-scale spatial cognition is thus, in part, the acquisition of the map-mediated view of these spaces. Culture can provide a way of thinking about space, but children still need to learn to understand it. Importantly, the map-mediated view of the world cannot simply be given or taught to young children. As the work of Vosniadou and Brewer (1992, 1994) demonstrates, children must make sense of what they learn about the world from maps and other representations; they must actively construct the knowledge, based in part on what they already know and in part on what they are learning. The researchers asked children to draw a picture of the world. This seemingly simple question led to some very complex responses. For example, children sometimes drew a circular or oblong earth (consistent with the globe), but then also included a flat section at the top of or inside the circle, to represent the "place where the people live." The fundamental challenge for children is to make sense of two seemingly contradicting ideas: They hear and see (from globes) that the earth is round, yet their personal experience indicates that the world is flat. This work clearly shows the constructive process of learning about the world beyond direct experience and the role of representations of large-scale space (the globe in this case) in the development of this understanding. The problem for children is not simply that they have to come to understand globes; they have to integrate what they know about the world with the information that comes from the globe, and in some cases, the two don't match.

These studies also point to ways in which we could enhance what the child learns about maps and the spaces that they represent. For example, using maps of spaces that are relatively large but familiar spaces might be particularly helpful. Children who might struggle to understand maps of very large-scale spaces often perform well when using maps of their school grounds or other familiar areas (e.g., Plester, Richards, Blades, & Spencer, 2002). Success in these sorts of tasks could provide a foundation for understanding the purposes of maps and the perspectives from which they are typically read. These experiences could provide footholds for understanding maps that represent larger spaces.

SUMMARY AND CONCLUSIONS

In this article, we have argued that spatial cognition is fundamentally an act of looking and thinking ahead and thus fits well within the prospective cognition perspective. In contrast to other species, humans rely greatly on culture and symbols to communicate information about space. Beginning around the age 3 years, young children learn to think about spatial location through symbolic representations, such as scale models. This initial development lays the foundation for many influences of spatial representations on spatial thought. Maps create a form of cultural ratchet; prior generations do not have to rediscover maps or the spaces that they represent because we can rely on the knowledge of prior generations. Maps provide a perspective on space that is difficult, if not impossible, to acquire from direct experience in the world. Much of the development of the cognition of large-scale spaces consists of acquiring this map-mediated view of the world.

We end by noting that the influence of maps is not static; the map-mediated model will change if our use of maps changes. For example, some commentators (e.g., Shasha, 2008) have expressed concerns that the nearly ubiquitous availability of Global Positioning Systems (GPS) may lead to decreases in the ability to think about and navigate large-scale space. GPS does the prospective cognition for us, planning a route without us having to think about the layout of the space through which we are traveling. Although these concerns may be unfounded, they are nevertheless consistent with the central claims of this article: Human conceptions of space are intimately connected to culturally constructed representations. When the representations change, we should not be surprised if the conceptions change as well.

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