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# PAPER

# Words and maps: developmental changes in mental models of spatial information acquired from descriptions and depictions

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## Abstract

*People acquire spatial information from many sources, including maps, verbal descriptions, and navigating in the environment. The different sources present spatial information in different ways. For example, maps can show many spatial relations simultaneously, but in a description, each spatial relation must be presented sequentially. The present research investigated how these source differences influence the mental models that children and adults form of the presented information. In Experiment 1, 8-year-olds, 10-year-olds and adults learned the layout of a six-room space either from verbal descriptions or from a map. They then constructed the configuration and pointed to target locations. Participants who learned from the map performed significantly better than those who learned from the description. Ten-year-olds performed nearly as well as adults did. The 8-year-olds' mental models differed substantially from the older children's and adults' mental models. The younger children retained the sequential information but did not integrate the relations into a survey-like cognitive map. Experiment 2 demonstrated that viewing the shape of the configuration, without seeing the map in full, could facilitate 8-year-olds' use of the verbal information and their ability to integrate the locations. The results demonstrate developmental differences in the mental representation of spatial information from descriptions. In addition, the results reveal that maps and other graphic representations can facilitate children's spatial thinking by helping them to transcend the sequential nature of language and direct experience.*

## Introduction

Spatial information can be acquired from a variety of sources. We often learn about our environment from direct experience, such as walking or driving. However, we also rely extensively on information acquired from indirect sources, such as maps, blueprints and schematic diagrams (Liben, 2001; Liben & Downs, 2001, 2003; Liben, Kastens & Stevenson, 2002; Presson, DeLange & Hazelrigg, 1989; Taylor & Tversky, 1992a; Uttal, 2000; Uttal & Wellman, 1989). The present research investigated how children and adults acquire spatial representations from verbal descriptions and maps. Our goal was to determine whether, and how, the source of spatial information affects children's mental representations of spatial information. More specifically, we investigated whether children could build mental models from these information sources, and if so, what the nature of the models might be. We also investigated the advantages and disadvantages of learning about spatial relations from verbal descriptions and from maps.

Most research on the influences of different forms of information on spatial cognition has focused on adults. This work has shown that adults form flexible, well-integrated spatial representations from both maps and verbal directions (Radvansky & Copeland, 2004; Taylor & Tversky, 1992a, 1992b). Taylor and Tversky (1992b) found that adults were able to draw maps of and make inferences about spatial layouts, regardless of whether they learned the spatial information from a map or from a description. These results are surprising and in some ways paradoxical. When adults *provide* descriptions, they tend to give only the serial information that reflects how the information would be experienced during navigation. For example, adults typically describe the layout of their residence as if walking through it, describing one room at a time in the order in which each room would be experienced (Linde & Labov, 1975). Yet when they

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hear similar descriptions, adults typically represent the information as if it were in a map-like survey form.

In the present research, we took a developmental approach to understanding the influences of different types of information on mental representations of space. We investigated the developmental origins of adults' competence in representing spatial information regardless of the source. We suggest that the apparently seamless use of spatial information from different sources that Taylor and Tversky demonstrated in adults may have important developmental antecedents. We hypothesized that young children form mental models of spatial information from descriptions that differ from those of adults. In contrast to older children and adults, younger children may be less likely to integrate the information in spatial descriptions into a survey-like mental model. Young children's mental models may reflect how the information is acquired more than adults' mental models do.

This hypothesis is derived from a synthesis of the results of two lines of prior work. The first concerns fundamental differences in how information is presented in maps, verbal directions and in direct experience. In a verbal description, each spatial relation must be described individually, and the spatial information therefore is presented sequentially (see Levelt, 1982; Linde & Labov, 1975). In contrast, maps typically allow people to see and organize many spatial relations at once (Liben, 1999, 2001; Sandberg & Huttenlocher, 2001; Taylor & Tversky, 1992a, 1992b; Uttal, 2000). Maps and verbal directions also support different kinds of judgments and cognitive processes. When looking at a map (or after memorizing one), judgments can be made about multiple spatial relations almost simultaneously. In contrast, when listening to verbal directions, people may have more difficulty making judgments about relations that were not specifically described. To make judgments about spatial relations that were not included in the descriptions, the spatial information must be *integrated* into a format that transcends the serial nature of the presentation (Bransford & Franks, 1971; Curiel & Radvansky, 2004; Johnson-Laird, 1989; Taylor & Tversky, 1992a, 1992b; Uttal, 2000). As used here, the term *integrate* means to assemble spatial locations into a mental model that includes multiple relations among multiple locations and affords judgments about those relations.

The extra cognitive demands associated with integrating the spatial information in a description might tax young children's thinking considerably. To integrate spatial memory into a map-like survey representation (as Taylor and Tverksy have shown that adults do), the child (or adult) would need to hold in spatial memory the relations among multiple locations as they were described, or as the relations were recalled. As each new location is added, the child must keep in mind the relations among the previously described locations as well as the relation of the newly added location to each of the existing locations. Limitations on children's memory for spatial information might make it difficult for them to hold simultaneously in working memory the spatial relations among many different locations (Kail, 1997; Kail & Bisanz, 1992).

The second line of prior research concerns developmental differences in children's mental representation of spatial information acquired from direct experience navigating in the world. Young children's representations are often based on the serial order in which information is acquired. For example, young children's representations of large-scale environments tend to be sequential in nature (Allen & Kirasic, 1985; Herman, Shiraki & Miller, 1985; Piaget, Inhelder & Szeminska, 1960; Siegel & White, 1975). These representations capture the serial order in which landmarks or routes are experienced but they may not encode the spatial relations among locations, particularly if the locations were not experienced together on a route. Additionally, Plumert and colleagues (Plumert, 1996; Plumert, Carswell, De Vet & Ihrig, 1995; Plumert, Ewert & Spear, 1995) have shown that young children's descriptions of spatial relations, as well as their interpretation of descriptions, focus on serial connections between specific locations and independent landmarks. If the same holds true for information that children acquire from spatial descriptions, then we would expect that young children might not integrate the information from serial descriptions into a survey-like cognitive map. In summary, prior empirical and theoretical work leads us to hypothesize that there will be developmental differences in the acquisition and use of information from verbal descriptions and from maps.

Very few studies have investigated specifically children's acquisition of spatial information from verbal descriptions. One study (Ondracek & Allen, 2000) did find developmental differences in spatial representations acquired from descriptions. Children heard a description of various spaces, such as a music room in a preschool or the backyard of a neighbor. The descriptions included information about the locations of objects within the spaces as well as the activities that could be performed. After hearing the descriptions, the children performed two tasks to assess their mental representations. In the *sentence verification* task, children answered yes/no questions about the activities that could be performed in the room and the locations of objects. Statements about activities were purely factual and semantic, such as 'The children enjoy marching and playing the drums' (p. 7). Some of the statements about locations involved spatial relations that had been specified in the descriptions.

Other location statements involved spatial relations that were not in the descriptions and hence required spatial inferences. All age groups performed well on questions, both factual and spatial, that queried information that was explicitly described. Only the older children, however, were able to answer spatial inference questions. In the second task, *map construction*, the children placed flags on a map to indicate the relative positions of objects in the described spaces. The younger children performed poorly.

Ondracek and Allen's (2000) explanation for the difficulty that the younger children had in making inferences was that they did not form spatial mental models from the descriptions. This explanation suggests that the activity and location information were represented in similar ways – as isolated, semantic facts. The children either did not or were not able to integrate the descriptions into a coherent model of the locations of objects in the described spaces. Consequently, they could only answer questions that referred to specific facts that they had heard (and remembered).

In this paper we present and test an alternate account of how children represent and use spatial descriptions. We hypothesize that at least by age 8, children do form mental models that include spatial information, but these models may differ fundamentally from those of older children and adults. We demonstrate that there are developmental changes in the mental representations that children form from hearing descriptions of a space. Specifically, young children's representations are more beholden to the sequential ordering of the information in the descriptions than are older children's and adults' representations. The mental representations that young children form from descriptions reflect the sequence with which the information was presented.

In Experiment 1a, we investigated the form of the mental models that children acquire from verbal descriptions and from maps. We asked 8-year-olds, 10-year-olds and adults to memorize the description of a relatively simple configuration or to learn the layout from a map. Participants then performed a pointing task (pointing to target locations) and a construction task (arranging cards to represent the space). These tasks revealed the format of participants' mental models of the space.

In Experiment 2, we investigated how viewing a simple diagram or map indicating the general shape of the environment, but not the specific locations, might facilitate children's thinking about spatial relations. Because maps permit direct access to spatial relations without requiring inferences about relations, we expected children who heard the descriptions after they saw the general shape of the configuration would perform substantially better on both tasks, especially when they needed to infer spatial relations.

## Experiment 1a

In Experiment 1a, participants first learned the layout of the space from a map or from a description. We assessed how the two groups represented and used the spatial information that they acquired.

### *Method*

#### Participants

Participants for all experiments were recruited from the same sources and in the same manner. Children were recruited through direct mail to their parents, and approximately 80% of the adults were university students who received course credit. The remaining adults were community members who had expressed interest in participating in psychology research; these participants were paid $10.

The participants for Experiment 1a were 48 8-year-olds (*M* Age = 101.4 months, range = 96–108 months), 48 10-year-olds (*M* Age = 124.4 months, range = 120–132 months) and 48 adults (*M* Age = 230 months, range = 217 months to 273 months). Two additional 8-year-olds started the study but did not complete the learning phase.

#### Apparatus and materials

The test space was a 6 × 6 × 7 ft (1.82 × 1.82 × 2.13 m) structure. PVC pipes formed the boundaries of the room, and the walls were blue curtains suspended from the pipes. The room was placed within a larger (12 × 18 ft) (3.66 × 5.49 m) testing space, along with a small table at which participants sat when performing some of the tasks. A cardboard arrow spinner, a block and a ball were used to define directions (e.g. left and right). The map was made of cardboard and consisted of six squares arranged in a 2-row by 3-column grid (see Figure 1). Each square in the grid was 6 in by 6 in; the scale that related the map to the represented space was 1 to 12. Six stuffed animals (pig, cat, rabbit, dog, bear and frog) were used to identify the different rooms. We used a small bucket to prop up the animals in the test space. Cutout photographs of the animals were placed on the map to indicate the animals' rooms. A second set of cutout photographs was also attached to square cards, which participants used to construct a model of the layout.

#### Procedures

Half of the participants (the *map* group) were assigned randomly to learn the layout from a map. The remaining

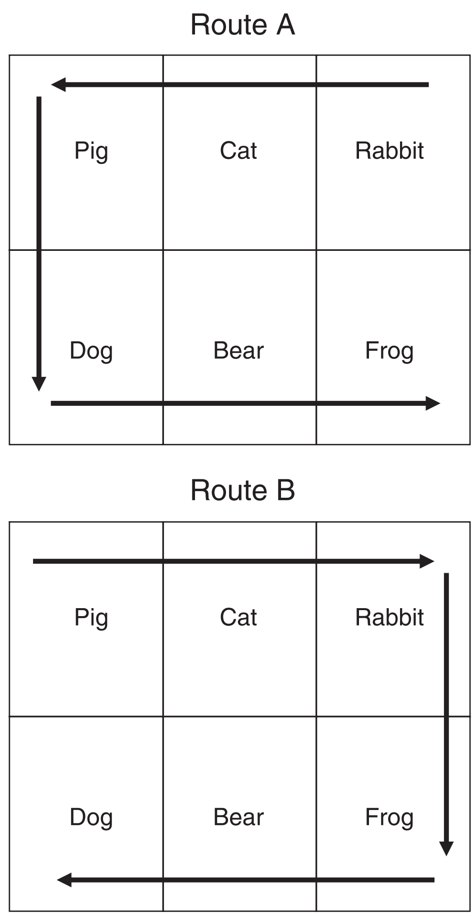


**Figure 1** *Layout of the six-room configuration, showing the two routes. On the actual map, the rooms were identified by cutout photographs.*

participants (the *description* group) learned the layout from the verbal descriptions provided in Table 1. The procedures for the two groups were designed to be as similar as possible. For example, the map and description group learned the animal locations in the same orders. In addition, the descriptions were written from a survey-like perspective; children who learned from descriptions were asked to think about the space as if they were looking at a map or model.

Each session began with the experimenter and the participant seated at the table, facing the test space (see Figure 1). The experimenter told participants that they would learn where six animals lived in six rooms that were all connected. Next, the experimenter said that the participants would not see all six rooms at once; instead they would see only the one room in the middle of the testing space. Finally, the experimenter told the participants that each time they entered the room, they were to imagine themselves in a different animal's room, with the other animals' rooms around them. The experimenter then presented the stuffed animals and asked the participant to identify each by name.

To help clarify spatial terms, the experimenter placed the arrow on the table, along with a ball on the left and a block on the right of the arrow. The experimenter pointed the arrow to the ball and block to define left and right respectively. Then the experimenter pointed the arrow toward the participant. Because the description required participants to imagine that they were looking down on the layout, this direction indicated that the room closest to the participant was 'in front' of the room farthest from the participant. In the map condition, no arrow was used because the relations were shown and not described.

When participants said that they understood the preliminary instructions, the experimenter began the training. The experimenter explained that he or she would tell the participant where each animal lived in the house. If the participant was assigned to the description group, the experimenter said, 'I would like you to imagine a model or map of the animals' house on the table in front

**Table 1** *Verbal descriptions*

| Experiment 1a | |
|---|---|
| Description A | Description B |
| The cat's room is on the left side of the rabbit's room.<br>The pig's room is on the left side of the cat's room.<br>The dog's room is in front of the pig's room.<br>The bear's room is on the right side of the dog's room.<br>The frog's room is on the right side of the bear's room. | The cat's room is on the right side of the pig's room.<br>The rabbit's room is on the right side of the cat's room.<br>The frog's room is in front of the rabbit's room.<br>The bear's room is on the left side of the frog's room.<br>The dog's room is on the left side of the bear's room. |
| **Experiment 1b** | |
| Description A | Description B |
| The cat's room is on the left side of the rabbit's room.<br>The pig's room is on the left side of the cat's room.<br>The dog's room is behind the pig's room.<br>The bear's room is on the right side of the dog's room.<br>The frog's room is on the right side of the bear's room. | The cat's room is on the right side of the pig's room.<br>The rabbit's room is on the right side of the cat's room.<br>The frog's room is behind the rabbit's room.<br>The bear's room is on the left side of the frog's room.<br>The dog's room is on the left side of the bear's room. |

of you. I will describe the rooms as if I'm describing this model or map.'

The layout of the house was described or depicted on the map in one of two counterbalanced orders (see Figure 1 and Table 1). Participants in the description group learned one of the two descriptions in the top portion of Table 1. The experimenter read the descriptions, one sentence at a time. Participants repeated each sentence after the experimenter read it. The experimenter then confirmed that the participant had learned the description with follow-up questions. For example, the sentence, 'The cat's room is on the left side of the rabbit's room', prompted the question, 'Where does the cat live?' New information was added only after the children had memorized all of the previous sentences. This procedure was repeated until the participant could say the entire description twice in succession without error.

The map-learning procedure was designed to be as similar as possible to the description-learning procedure. The map group learned the layout one room at a time. The experimenter placed the cutout photographs in the middle of each square on the map, one by one, and said, 'This is the __'s room. Can you point to where the __ lives?' For each new animal added, the entire set of animals was repeated until all six animal photographs were positioned correctly on the map outline (see Figure 1). The order of presentation of the animals in the map condition was the same as the order in the descriptions (see Table 1). The experimenter allowed participants to study the map for as long as they wished before removing all study materials from sight.

### Test phase

After participants met the learning criteria, we assessed their knowledge with the model *construction task* and the *pointing task*. The order of the tasks was counterbalanced.

The construction task took place at the table. The experimenter handed the participants six cards that depicted the animals' rooms in a randomly ordered stack. The participants were asked to arrange the cards according to the layout of the house. The experimenter recorded the final position of the cards in a diagram. Participants were allowed to move cards or correct their constructions until they were satisfied that the layout was correct.

In the pointing task, the experimenter and the participant entered and exited the test space six times. The participants were asked to imagine that each time they entered the test room, they were walking into a different animal's room. Before each trial, the experimenter placed a different animal in the bucket in the test room. The participant and the experimenter then entered the test room and both stood oriented in the same way as they did during the learning phase. The experimenter told participants to imagine themselves in the animal's room and to point to where three other animals' rooms would be. For example, on one trial, participants saw the pig in the center of the room and they were asked to imagine that they were in the pig's room. Then they were asked to point to the cat's, dog's and bear's rooms (see Table 2 and Figure 1). Participants completed 18 points, three from each animal's room. The experimenter recorded the points in terms of one of eight possible directions: front, back, left, right and the four intermediate diagonals.

**Table 2** *Points requested from each imagined room*

| Reference room | Target rooms | | |
|---|---|---|---|
| Rabbit | Cat | Dog | Bear |
| Cat | Rabbit | Pig | Frog |
| Pig | Cat | Dog | Bear |
| Dog | Rabbit | Pig | Frog |
| Frog | Cat | Dog | Bear |
| Bear | Rabbit | Pig | Frog |

## *Results*

### Overview

We analyzed the results to address two general questions. The first was whether participants' representations included the spatial relations that were described or depicted. The second was whether the participants encoded the linear order of the relations that they learned in the study phase, and whether their representations included inferred relations. The two tasks (construction and pointing) provided converging evidence relevant to both questions.

Separate analyses were conducted to test whether children's performance was influenced by their gender, or by the order in which they completed the test-phase tasks (pointing first or construction first). Results of these analyses are reported only when there was a significant effect or interaction involving gender or task order. In all other cases, we pooled the data across these variables.

### Construction task results

We first classified the constructions into three accuracy categories; Figure 2 provides examples of each. Constructions were classified as *correct* only if each card was placed in the correct relative position (see Figure 1). Constructions were classified as *incorrect but preserved shape* if they preserved the shape of the target configuration but contained errors in terms of the placements of individual

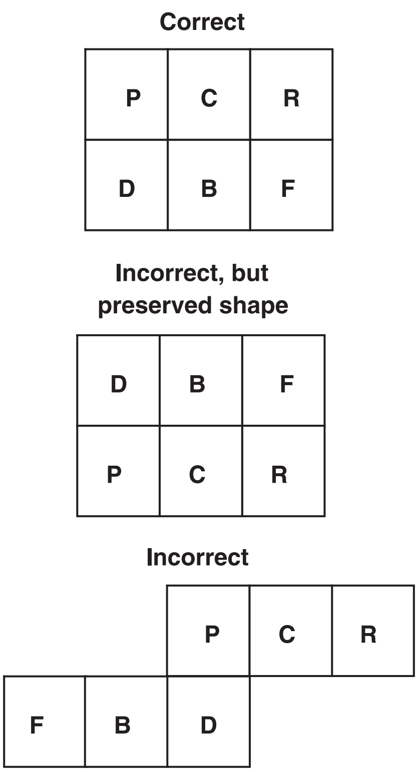


**Figure 2** *Examples of the three categories of constructions.*

**Table 3** *Frequency of construction types, Experiment 1a*

| | | Condition | |
|---|---|---|---|
| Construction type | Age | Description | Map |
| Correct | 8 | 2 | 20 |
| | 10 | 11 | 22 |
| | Adult | 16 | 21 |
| Incorrect but preserved shape | 8 | 10 | 4 |
| | 10 | 4 | 2 |
| | Adult | 7 | 3 |
| Incorrect | 8 | 12 | 0 |
| | 10 | 9 | 0 |
| | Adult | 1 | 0 |

animals. Examples include switching the position of two rooms or of the two rows in the configuration. The remaining constructions were classified as *incorrect*; these configurations contained errors in the overall shape and in the relative position of the cards.

Table 3 shows the distribution of the three types of constructions as a function of age and condition. Participants in the map group performed well, regardless of age. Most of the constructions of the map-group participants were classified as correct, and not one was classified as incorrect. A chi-square test revealed no age differences in the distribution of construction types in the map group.

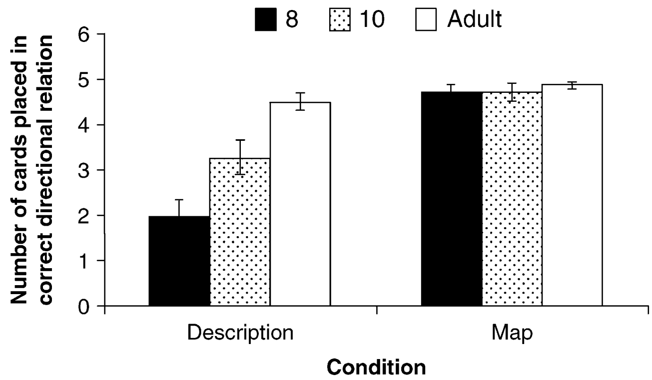


**Figure 3** *Number of correct directional relations in the constructions.*

In contrast, there were large age differences in the distribution of construction types in the description group, $\chi^2$ (4, $N$ = 72) = 21.80, $p$ < .001. The 8-year-olds' constructions were significantly less accurate than those of the 10-year-olds or adults, $\chi^2$s (2, $N$ = 48) > 9.23, $p$s < .01. Overall, the 10-year-olds' constructions were less accurate than those of the adults, $\chi^2$ (2, $N$ = 48) = 8.14, $p$ < .05. The 10-year-olds' performance was essentially bi-modal; most of their constructions were either correct or incorrect. Only four of the 24 constructions of 10-year-olds in the description group were classified as incorrect but preserved shape.

We also conducted a second, converging assessment of the spatial properties of the constructions. We counted the number of pairs of cards that were placed in the correct left-right or front-back direction relative to each other. For example, in Order A, constructions received one point if the cat was placed to the left of the rabbit, another point if the pig was placed to the left of the cat, etc. The correct configuration contains five unique paired relations (see Figure 1). For Order A, the pairs were rabbit-cat, cat-pig, pig-dog, dog-bear and bear-frog. For Order B, the pairs were pig-cat, cat-rabbit, rabbit-frog, frog-bear and bear-dog. We awarded one point for each correct relative direction in the construction. The resulting *direction score* ranged from zero (no directional relations preserved) to 5 (all unique left-right relations preserved).

A 3 (Age) by 2 (Condition) ANOVA on the direction score revealed a significant Age by Condition interaction, $F$(2, 138) = 11.05, $p$ < 001. As shown in Figure 3, adults performed well in both conditions, but both the 8- and 10-year-olds in the map condition performed better than their agemates in the description condition, $F$s(1, 138) > 15.64, $p$ < .001. Overall, 8-year-olds' constructions were inaccurate in terms of spatial relations, and adults' constructions were very accurate. The 10-year-olds differed significantly from both groups. Analysis

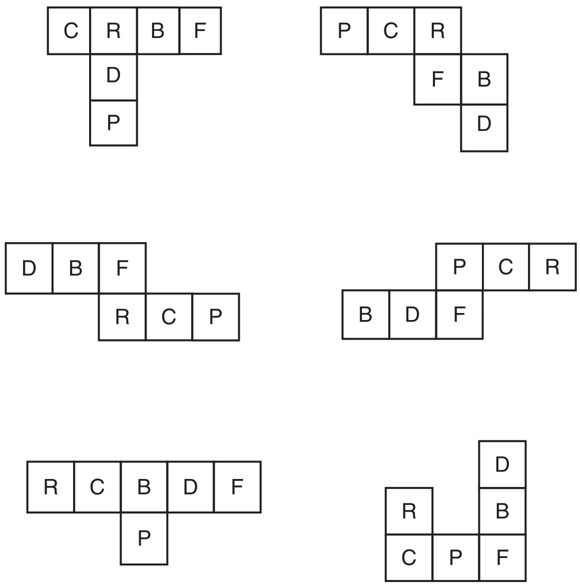


**Figure 4** *Examples of the 8-year-olds' constructions.*

of individual performance was consistent with the average levels of performance: three, eleven and seventeen of the constructions of the 8-year-olds, 10-year-olds and adults, respectively, in the description condition preserved all of the left-right relations, $\chi^2$ (2, $N$ = 72) = 16.77, $p$ < .001.

Because so many of the 8-year-olds' constructions were classified as incorrect, we examined these constructions in greater detail. Figure 4 shows several examples. This figure confirms that most of the constructions do not preserve the specific spatial relations in the target configuration. However, it also reveals that the children's constructions are far from random. For example, even though the constructions differ from the target, and from each other, they nevertheless preserve the contiguity relations from the descriptions.

In the next analysis, we tested formally whether the constructions reflected the sequential pairing or ordering of animals that were described, regardless of whether the participant placed the cards in the correct spatial (e.g. left-right) relation. This analysis was based on the same pairings of animals as in the calculation of the direction score. However, in this case, we counted a pairing as correct if it reflected the order in which the relations were described. A pair of cards was scored as contiguous only if the two construction cards were placed in contact with each other and fully shared a border. Rooms that touched diagonally, without fully sharing a border, were not scored as contiguous. We summed the number of correct contiguity relations for each participant. The resulting *contiguity score* ranged from zero (no contiguity relations preserved) to 5 (all contiguity relations preserved).

The constructions of participants in all groups preserved the sequential information in the descriptions. The result was revealed in a 3 (Age) by 2 (Condition) ANOVA on the contiguity score. Only the main effect of condition was significant, $F$(1, 120) = 6.3, $p$ < .05; the map group ($M$ = 4.8, SD = 0.7) performed better than the description group ($M$ = 4.4, SD = 1.0). The lack of a significant effect of age is noteworthy; even the 8-year-olds preserved more than four out of the five contiguity relations. That even the youngest children preserved the contiguity relations is consistent with our hypothesis that they form mental models from the descriptions, but base them on the sequential information in the descriptions; even the youngest children's constructions captured the 'next to' information that was presented both in the descriptions and on the map.

## Pointing task results

In the pointing task, we asked participants to use the information that they had gained from the descriptions or from the map to make judgments about different relations among locations (see Table 2). Of particular interest in this regard are points that involve relations that were not described. The best test of whether participants could infer the spatial relations that were not explicitly described are the points involving diagonal relations (see Figure 1). These relations were never described and always involved animals in different rows. The diagonal relations therefore cannot be easily inferred by transitive inference but instead require spatial inference.

The percentage of correct diagonal and straight points were analyzed in a 3 (Age) by 2 (Condition) by 2 (Target Direction of Point: Diagonal versus Straight) ANOVA, with target direction of point as a within-subjects factor. The interaction between target direction of point and condition was significant, $F$(1, 132) = 13.76, $p$ < .001. As shown in Figure 5, the description group performed substantially worse on the diagonal points than on the straight points, $F$(1, 66) = 33.04, $p$ < .001. In contrast, participants in the map group performed comparably on the straight and diagonal points, $F$(1, 66) = 1.08, *ns*. The main effect of condition was also significant, $F$(1, 132) = 16.79, $p$ < .001. The map group performed significantly better than the description group. The main effect of age was also significant, $F$(2, 132) = 24.60, $p$ < .001. Scheffé post-hoc contrasts revealed that the 8-year-olds performed worse overall than the 10-year-olds and adults did; the latter two groups did not differ significantly from each other. It is also interesting to note that there was no three-way interaction, indicating that the diagonal

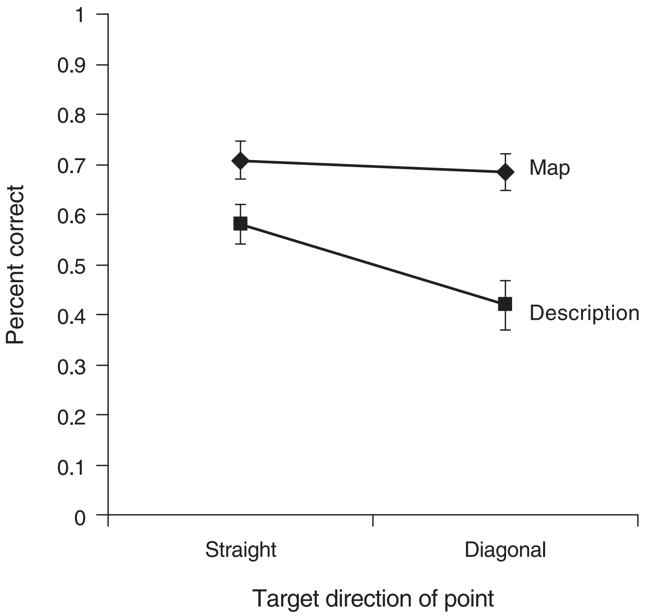


**Figure 5** *Percent correct points as a function of direction of target and condition.*

points were relatively difficult, even for adults. Thus, in general adults were accurate overall, yet they still found the inference questions to be challenging.

### Relative assessment

The analysis of the absolute pointing score reveals that the 8-year-olds did not point as well as the older children and the adults. Note, however, that the first assessment of the points was based on the assumption that all participants acquired the same mental model of the spatial relations, and that this model captured the spatial relations as they are shown in Figure 1. The analyses of the constructions suggests that the 8-year-olds' mental models of the spatial information may have differed fundamentally from the older children's and adults' models. Pointing according to a model that differed from the target configuration could obviously lead to a poor assessment. We therefore rescored the points, using the children's individual constructions as the correct model. That is, we scored a point as correct if the direction of the participant's point corresponded to the comparable direction in his or her construction. This analysis of a relative pointing score reveals that children were able to perform the pointing task and that the description-group 8-year-olds pointed in a manner that was consistent with their serial representations of the descriptions.

Table 4 gives the means and standard deviations for the relative pointing score. In contrast to the analyses of the absolute pointing score, the main effect of condition was not significant. The ANOVA produced a significant age effect for the relative pointing score, $F(2, 120) = 23.5$, $p < .001$. Although post-hoc comparisons revealed that 8-year-olds performed significantly worse than did 10-year-olds and adults ($p < .001$), the latter two groups did not differ from each other. The only other main effect or interaction to reach significance was a sex by condition interaction, $F(2, 120) = 4.6$, $p < .05$, driven by the fact that the 10-year-old girls performed better than the 10-year-old boys, especially in the map condition.

**Table 4** *Mean number of correct points as assessed by the relative criterion*

| | | Age | | |
|---|---|---|---|---|
| Condition | | 8 | 10 | Adult |
| Description | *M* | 7.8 | 13.8 | 13.7 |
| | SD | 5.1 | 5.1 | 5.5 |
| Map | *M* | 9.3 | 13.7 | 15.8 |
| | SD | 4.8 | 4.7 | 3.6 |

*Note*: Maximum score is 18 in both cases.

### *Discussion*

The results of Experiment 1a reveal developmental differences in children's ability to form and use mental representations based on different sources of spatial information. As predicted, almost all participants who learned the configuration from a map performed well, regardless of age. In contrast, most of the 8-year-olds and some of the 10-year-olds who learned from the descriptions performed differently than the adults did. On the one hand, their representations were not accurate in an absolute sense. On the other hand, they did form a mental representation from the descriptions, one that supported consistent performance across the tasks. Taken together, the results indicate that the 8-year-olds did acquire and use spatial information from the descriptions and that they formed a coherent mental model from the descriptions. However, their model differed fundamentally from that of the older children and the adults.

The results indicate that children's mental models of spatial descriptions are based on the serial and contiguous format in which spatial information must be conveyed in words. Two results support this conclusion. First, although the constructions of the 8-year-olds in the description condition were not accurate in an absolute sense, their constructions preserved on average more than four of the five contiguity relations based on these descriptions. This result indicates that all 8-year-olds could remember the descriptions but represented them differently than older children and adults did. The 8-

year-olds thought of the descriptions in terms of the serial ordering of the individual spatial relations. They built a mental model that captured the ordering of the relations as they heard them in the descriptions, but they did not integrate these individual relations into a survey-like mental map (see Figure 4). Thus the 8-year-olds, in contrast to the 10-year-olds and adults, did not transcend the way in which language presents spatial information, as a series of individual relations.

Second, the pointing task results reveal the characteristics of the participants' mental representations. We first assessed all participants according to the relations that were depicted on the map. This analysis revealed that the 8-year-olds in the description condition performed poorly, particularly on the diagonal inference points. In contrast, the 8-year-olds in the map group performed much better, and they performed comparably on the diagonal and straight points. The relatively high level of performance of the map-group children on the diagonal points helps to rule out the possibility that pointing to the diagonal was in general difficult for the younger children (Olson, 1970; Somerville & Bryant, 1985). The fact that the map group participants (including the 8-year-olds) could perform the diagonal points suggests that children could point correctly to the diagonal.

When we assessed the points according to a different standard, a very different picture emerged. The second standard was the child's own construction, which provides an indication of the mental model that the child formed from the descriptions or map. The 8-year-olds in the description group performed much better on this assessment, and the map and description groups performed comparably. They were even able to point accurately for some of the relations that were not explicitly described. Thus the 8-year-olds could perform the pointing task and could make spatial inferences, but they pointed on the basis of a mental model that differed from that of the older children and adults.

The results therefore present a new perspective on what 8-year-olds learn from hearing spatial descriptions. Our results clearly indicate that they are capable of using elements of the spatial information. They do not simply represent the sentences in the descriptions as unrelated semantic facts. They represent the information sequentially, as it is presented in the descriptions. Moreover, they can make inferences about relations that were not described. The inferences are derived from the mental models that they formed and used consistently but which were not accurate in an absolute sense. The representations of the older children and adults were more accurate in an absolute sense. In Experiment 1b, we investigated whether this effect was limited to the particular description used in Experiment 1a.

## Experiment 1b

The results of Experiment 1a indicate that many of the younger children formed mental representations from descriptions but that their mental models differed from those of older children and adults. Could these results be due to characteristics of the particular descriptions that we used? The description in Experiment 1a took a perspective that differed from how people experience a space when they navigate through it: the participants were asked to imagine that they were looking down on the space, more like looking down on a map. One might argue that adopting this perspective would be particularly difficult for the younger children (Liben & Yekel, 1996; Shantz & Watson, 1971). Thus it seemed possible that the specific challenge that children faced in Experiment 1a might have stemmed from the perspective-taking demands of the task, rather than from the need to integrate the spatial descriptions. In Experiment 1b, we examined whether the 8-year-olds would perform better if the descriptions took a perspective that was more viewer-centered and did not require imagining a top-down perspective.

In Experiment 1b, participants were told that they were to imagine themselves inside the space as they learned the descriptions. The new perspective encouraged participants to build their representation by imagining the environment one room at a time from inside the configuration. This is not a classic route perspective in that children were not asked to imagine that they were traveling through the various rooms (Perrig & Kintsch, 1985; Taylor & Tversky, 1992a, 1992b). Instead, this perspective corresponded to how the children would be asked to use the information during the pointing task. If the results of Experiment 1a were due specifically to the perspective-taking challenges of our Experiment 1a description, then children could potentially perform better with a different description.

### *Method*

#### Participants

The participants were 24 8-year-olds ($M$ Age = 101.4 months, range = 96–107 months), 24 10-year-olds ($M$ Age = 125.4 months, range = 120–132 months) and 24 adults ($M$ Age = 234.9 months, range = 216–322 months). There were equal numbers of males and females in each age group. None of the participants from Experiment 1a participated in Experiment 1b.

#### Materials

All materials were identical to those of Experiment 1a, except for the descriptions.

### Procedures

The procedures were similar to those of the description condition of Experiment 1a (see Table 1), with two exceptions. First, when participants were learning the descriptions, they were told to think of themselves as being inside the test space. Second, the descriptions were changed to correspond to the new perspective. The description of Experiment 1b took a viewer-centered perspective and consequently spatial terms were defined using the axes of the viewer's body (Clark, 1973; Taylor & Tversky, 1992a). Because the viewer-centered description required that participants imagine themselves inside the animals' house, the application of the terms 'behind' and 'in front' was reversed. When we placed the arrow facing toward the participant (e.g. past them or toward their back), we now defined this direction as 'behind'. In Experiment 1a, the same direction had been defined as 'in front'.

### *Results and discussion*

Participants in Experiment 1b performed similarly to those in Experiment 1a. As before, we classified the constructions as correct, incorrect but preserved shape, or incorrect. The distribution of the types of constructions again varied significantly by age, $\chi^2$ (4, $N$ = 72) = 12.41, $p < .05$, with the younger participants producing more incorrect constructions and the older participants producing more correct productions. Thirteen, seven and two of the classifications of the 8-year-olds, 10-year-olds and adults, respectively, were classified as incorrect. In contrast, 6, 7 and 11 of the constructions of the 8-year-olds, 10-year-olds and adults, respectively, were classified as correct. The remaining constructions were classified as incorrect but preserved shape. Table 5 gives the means and standard deviations for the direction and contiguity scores. A 2 (Experiment) by 3 (Age) by 2 (Condition) ANOVA showed no main effects or interactions involving experiment, and the main effects and interactions replicated those reported in Experiment 1a.

The participants in Experiment 1b also performed similarly to those in Experiment 1a on the pointing measures. Table 6 provides the means and standard deviations for the diagonal and straight points. ANOVA again showed no main effects or interactions involving experiment.

**Table 5** *Means and standard deviations for the direction and contiguity assessments of the constructions in Experiment 1b*

| Measure | | Age 8 | 10 | Adult |
|---|---|---|---|---|
| Direction | *M* | 2.6 | 3.5 | 4.3 |
| | SD | 1.8 | 1.4 | 0.9 |
| Contiguity | *M* | 4.5 | 4.4 | 4.3 |
| | SD | 0.9 | 1.0 | 0.9 |

**Table 6** *Mean percentage correct (and standard deviations) for the diagonal and straight points in Experiment 1b*

| Direction of point | | Age 8 | 10 | Adult |
|---|---|---|---|---|
| Diagonal | *M* | 24.5 | 38.0 | 43.2 |
| | SD | 36.8 | 38.7 | 39.9 |
| Straight | *M* | 47.5 | 56.3 | 75.4 |
| | SD | 32.4 | 32.1 | 25.9 |

The results of Experiment 1b therefore indicate that the findings are not specific to the perspective that we used in our descriptions, giving credence to the generality of our findings. In other words, regardless of the perspective from which the descriptions are presented, 8-year-olds formed mental models that were tied to the sequential relations in the descriptions.

## Experiment 2

The results presented thus far indicate that 8-year-olds form different mental models from descriptions than older children and adults do. The 8-year-olds in Experiments 1a and 1b represented the spatial information as they had encountered it in the descriptions. Their mental models of the spatial information were mostly tied to the serial nature of the descriptions. This raises the question of whether children are capable of forming an adult-like mental model from the descriptions. We investigated this question in Experiment 2 by providing the correct model explicitly to the children and then observing how this affected their interpretation and mental representation of the descriptions.

We hypothesized that a graphic spatial representation, such as a map or picture of the general configuration, may help children to think about spatial information in a manner that transcends direct experience, allowing them to think about multiple spatial relations simultaneously. Part of the advantage of using maps and spatial diagrams for spatial problem solving is that they help to constrain the possible mental models that people can form of the relevant spatial information. Effective diagrams present information in a way that optimizes problem solving and simultaneously prevents people from forming incorrect or ineffective mental models (Bauer & Johnson-Laird, 1993; Novick, 2001; Novick & Hurley, 2001). Graphic representations may influence spatial thinking and its development by providing a model that differs from the serial-based mental model that children typically form on the basis of direct experience and descriptions.

The performance of the map group in Experiment 1a is consistent with this hypothesis: children who saw the map performed much better than their counterparts who heard the descriptions. In Experiment 2 we sought to extend these results by investigating whether exposure to a graphic outline of the configuration could also influence children's conception of descriptions. We investigated the effects of providing children with a model that could help them transcend the serial nature of the descriptions without also simultaneously giving them access to the specific relations within that model. We showed children the outline of the spatial layout without providing information about the animals' specific locations. Then we taught them the verbal description from Experiment 1a. We predicted that seeing the general configuration would lead children to abstract the spatial properties of the descriptions and to form more adult-like mental models.

### *Method*

#### Participants

The participants were 24 8-year-olds (*M* Age = 102.5 months, range = 96 to 109 months) and 24 adults (*M* Age = 240 months, range = 221 to 273 months). Three additional 8-year-olds started the study but did not complete the learning phase.

#### Materials

We used the same cardboard outline as in Experiment 1a but without photographs attached. All other materials were identical to those of Experiment 1a.

#### Procedures

Participants learned the layout from the descriptions used in Experiment 1a (see Table 1). The procedures were identical to those of the description condition of Experiment 1a except that participants saw the outline before they learned the descriptions. Immediately before the participants began to learn the descriptions, the experimenter placed the outline on the table and said, 'This is how the rooms in the animals' house are arranged.' To facilitate comparisons, we refer to participants in Experiment 2 as the *outline* group.

### *Results*

We compared the performance of 8-year-olds and adults in Experiment 2 to the 8-year-olds and adults in the description group of Experiment 1a. We analyzed construction and pointing performance as in Experiment 1a.

#### Construction task

Eight-year-olds in Experiment 2 performed substantially better than their agemates in the description group in Experiment 1a. Ten of the 24 children in Experiment 2 constructed the configuration correctly. Twelve of the constructions were classified as incorrect but preserving shape, and only two were classified as incorrect. A chi-square test showed that the distribution of the construction types differed significantly among 8-year-olds in the two experiments, $\chi^2$ (2, $N$ = 48) = 12.66, $p < .01$.

A critical question concerns whether children preserved the directionality of paired relations in their constructions. This measure can reveal whether seeing the outline helped the children to think about the spatial relations among various locations. As in Experiment 1, we counted how many room pairs (out of 5) were placed in the correct left-right or front-back direction relative to each other. Children in Experiment 2 performed much better than did the 8-year-olds in Experiment 1. A 2 (Condition: Description or Outline) by 2 (Age) ANOVA comparing the performance of outline participants to the map and description groups in Experiment 1a revealed a significant interaction, $F(1, 92) = 5.80$, $p < 05$. Simple effects tests indicated that the performance of adults did not differ significantly in the two experiments; they performed well in all conditions, preserving on average more than four of the five directional relations in their constructions. In contrast, the constructions of the 8-year-olds in Experiment 2 preserved 80% more directional relations ($M$ = 3.54, SD = 1.72) than those of their agemates in Experiment 1a ($M$ =1.96, SD = 1.78), $F(1, 46) = 15.39$, $p < .001$.

#### Pointing task

As in the prior experiments, we considered the target direction of the points in analyzing pointing accuracy. We compared the performance of the outline group to that of the description group of Experiment 1a. A 2 (Condition: Description or Outline) by 2 (Age) by 2 (Point Direction: Straight or Diagonal) ANOVA on the proportion of correct points revealed a significant effect of condition. As predicted, participants who saw the outline before hearing the descriptions ($M$ = .61, SD = .36) performed significantly better than the description group in Experiment 1a ($M$ = .48, SD = .36), $F(1, 92) = 4.19$, $p < .05$. The main effects of age and direction were also significant; these replicate effects discussed previously.

### *Discussion*

As expected, 8-year-olds in Experiment 2 performed significantly better than those in Experiment 1a on all measures. The results suggest that seeing the outline helped children integrate spatial relations among multiple locations in accordance with the room arrangement they had seen. That is, as they learned the descriptions, children used the information about the overall shape of the space to form a more accurate representation. Thus seeing the graphic outline led the children to form a mental model that was no longer tied to the sequential properties of the description.

An alternative hypothesis could be that the outline led to good performance in the construction task without actually affecting how children thought about the descriptions. Perhaps children who saw the outline simply placed the cards down according to the outline they had seen earlier without actually thinking about the relation between the outline and the description. This alternative explanation suggests that the effect was on task performance and not on cognitive processes taking place during the learning phase.

However, the lack of an effect of order of task on children's performance suggests that this alternative hypothesis cannot account for the results. One-half of the children did the pointing task first, and their relatively good performance on the construction task indicates that they could point well without needing to refer to their own construction. Moreover, those who did the construction task first did not have the outline present during either of the tasks. In addition, many of the children moved the cards around several times, indicating that the representation was not previously set. Finally, we did not indicate with which room they should begin the construction, and yet the participants seemed to know both the order and the orientation of the rooms.

For these reasons, we conclude that seeing the outline (a) influenced how children thought about the spatial information in the descriptions, (b) highlighted the relevance of the spatial relations and (c) helped children transcend how the spatial relations were presented. Experiment 2 also demonstrated that once children formed a relatively accurate representation, they were able to use it. Because the only difference between the description condition in Experiment 1a and the outline condition in Experiment 2 was the brief viewing of the layout, we conclude that children's better performance can be attributed to knowing the general layout of the space before hearing the verbal description. Having a graphic cue helped children to transcend the serial nature of the descriptions and improved their ability to integrate spatial information.

## General discussion

Our results make two related contributions to research on the development of spatial cognition and diagrammatic reasoning. First, we extend understanding of the developmental course of children's mental representations of spatial information by delineating the nature of their mental models acquired from spatial descriptions and from maps. Study 1a established that most 8-year-olds are adept at creating and using mental representations based on information acquired from a simple map. However, in contrast to older children and adults, they are less likely to form fully integrated mental models when they learn a configuration from a verbal description. Instead, their mental models are based on the sequential nature in which information is presented in descriptions. Thus, we contend that 8-year-olds form mental representations of spatial descriptions, but the nature of the representation differs substantively from that of older children and adults. Evidence for this contention comes from the consistency in performance across our tasks. The 8-year-olds' points were consistent with their reconstructions of the configuration.

Second, the results shed light on possible influences of diagrams and diagrammatic reasoning on the development of spatial cognition. We have shown not only that looking at a diagram can facilitate children's reasoning about spatial relations but that this effect is not limited to those situations in which the specific spatial relations can be directly observed. Diagrams may facilitate spatial reasoning by highlighting ways of thinking about linguistically conveyed spatial information (Novick, 2001; Novick & Hurley, 2001). Our research demonstrates that they may also influence the development of children's comprehension of spatial descriptions.

Based on converging evidence from our two tasks, we conclude that the 8-year-olds did form a mental model from the descriptions, but this model involved a sequential series of locations. Inferences could then be made only on the basis of where something occurred along the path. In contrast, 8-year-olds who saw the map or the outline represented the information in a form that was not limited to the sequential information. Our results therefore shed light on how people acquire spatial representations from maps and from verbal descriptions. Adults' ability to acquire map-like representations from spatial descriptions (Taylor & Tversky, 1992a) has important developmental antecedents (see also Ondracek & Allen, 2000). Whereas 8-year-olds represented the descriptions as a series of contiguous relations, many 10-year-olds more fully integrated the descriptions. However, both groups learned the relations among the animals' rooms when they learned the layout from a map. Thus our results highlight similarities between children's representations of natural environments and their representations of verbal descriptions in that the younger children's representations were sequential in nature. Younger children remembered and formed mental models that were based on contiguity relations, whereas the majority of 10-year-olds and most adults formed representations that were survey-like.

What accounts for the developmental difference in how children and adults represented the information? We know that the developmental differences are not due only to the difficulty of the task or to children's limited memory for the descriptions. Almost all children completed the experiment, and more importantly, they pointed in a manner that was consistent with their representations. In addition, the contiguity scores indicate that even children who performed poorly on left-right and front-back directions nevertheless knew which rooms went together. Moreover, their points reflected how they represented the information. That the children in the map group in Experiment 1 and in the outline group in Experiment 2 performed better than the description group also indicates that children were not limited by task demands. However, unlike the adults, they did not integrate the information beyond the way in which it was presented in the descriptions. Thus the differences were not due to *whether* the 8-year-olds memorized the information but to *how* they memorized it.

Prior explanations for developmental differences in the integration of spatial information have focused on processing limitations (Kail & Bisanz, 1992; Siegel & White, 1975). Such limitations could have contributed to the developmental differences that we observed in the present studies. To integrate the information into a representation that captures the relations between all the locations, the children would simultaneously need to remember the information and to think about an alternative way in which it could be represented. Extra processing is required to simultaneously think about possible configurations while figuring out how the specific information integrates into a shape. Children appear to be capable of remembering the information that is required but have difficulty figuring out how the information could be integrated into an alternative format.

Our explanation for the developmental differences in the mental models that the participants formed also helps to shed light on the benefits of studying the map (Experiment 1) or the outline (Experiment 2). Children who saw the map in Experiment 1 performed well, but so did the children in Experiment 2 who received a brief visual cue concerning the outline of the space. Seeing the map or the outline constrained the number of possible interpretations of the descriptions. Children no longer had to figure out the shape of the configuration, but they still needed to figure out how the animals should be placed into the configuration as they listened to the description. The diagram, then, gave them a conceptual advantage concerning the arrangement of the configuration. This in turn reduced the processing demands associated with remembering both serial and configural information.

Our explanation can also be contrasted with another possible explanation, namely, that the 8-year-olds could not distinguish left and right and therefore preserved only the contiguity relations in their constructions. However, note that all children received, and passed, training to ensure that they knew and could use the terms left and right. In addition, children in Experiment 2 also had the same demands to remember and to understand left and right, as they had to learn the descriptions to figure out where the animals should go in the outline. The fact that 8-year-olds in Experiment 2 nevertheless performed well indicates that an absolute failure to distinguish left and right cannot account for the results. Rather, we believe that children in Experiment 1 did not realize that, or why, it was important to attend to the left-right relations. They were forming a mental model that was simply based on what animal came next in the room, regardless of spatial location. In Experiment 2, however, we changed the children's mental models by showing them the outline, and now the children did attend to the left-right relations.

In summary, we suggest that diagrams and maps influence spatial thinking in two related ways: by providing alternative models of how the spatial information can be organized and by reducing the memory demands associated with the processing demands of mentally representing spatial information. Learning to use maps and diagrams may contribute to helping children understand that spatial information can be represented in ways that differ from how it is encountered or experienced. The effects of learning to use maps and diagrams may eventually extend to situations in which children are not looking at a map; practice and experience in using these representations may lead children to think spontaneously of how the relevant information could be organized in a map-like way (Uttal, 2000, 2005).

## The development of skill in inferencing

Thus far we have focused on developmental changes beginning at age 8. We found that 8-year-olds, in contrast to older children and adults, did not fully integrate the spatial descriptions into a format that captured the spatial relations among all locations. However, this finding should not be taken as evidence that children of this age lack a general ability to integrate information. Research in other domains, such as reading and text comprehension, has shown that younger children can make inferences about other kinds of information. For example, even 5-year-olds have some ability to use hints or clues in stories to make inferences about information (Schmidt & Paris, 1983; Schmidt, Schmidt & Tomalis, 1984). The ability to make such inferences improves with age, with older children making more inferences and requiring less specific cues. It is important to note that in the present study the 8-year-olds did make some inferences, even though they did not acquire a fully integrated, survey-like representation. When we assessed their points in reference to the models that they constructed, we found that the 8-year-olds were able to infer some of the relations that were not described. If we take into account that children's mental models were tied to the serial nature of the descriptions, then we also found that young children make inferences about information that was not described. Thus, the difference between children and adults is not specifically in terms of whether they can make inferences, but whether they hold the inferred relations in memory simultaneously to form a survey-like cognitive map.

### Summary and conclusions

In summary, we have identified developmental differences in children's acquisition of spatial information from descriptions. In contrast to older children and adults, 8-years-olds formed mental models of spatial descriptions that reflect the serial nature of language. They did not integrate the descriptions into a survey-like cognition map. The results also demonstrate that maps, diagrams and other external spatial representations may encourage people to think about multiple spatial relations, and thus transcend direct experience (Blades, 1989; Blades & Spencer, 1994; Bremner & Andreasen, 1998; DeLoache, 1995a, 1995b, 2000; Liben, 1999, 2001; Liben & Downs, 2001, 2003; Liben *et al.*, 2002; Uttal, 2000, 2005). Diagrammatic representations may influence children's thinking in part by making them aware of alternative ways of thinking about spatial information. By presenting a perspective that highlights spatial relations, maps and other diagrams help people to transcend the limits of their own perception. Spatial representations may therefore have important educational applications because they help young children to think about information in a manner that is not always immediately available to perception. Using diagrams and charts could facilitate thinking in many domains, such as fractions and geometry, in which children must think simultaneously about multiple spatial relations.

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