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Developing symbolic capacity one step at a time ☆

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Abstract

The present research examines the ability of children as young as 4 years to use models in tasks that require scaling of distance along a single dimension. In Experiment 1, we found that tasks involving models are similar in difficulty to those involving maps that we studied earlier (Huttenlocher, J., Newcombe, N., & Vasilyeva, M. (1999). Spatial scaling in young children. *Psychological Science, 10*, 393–398). In Experiment 2, we found that retrieval tasks, where children indicate the location of a hidden object in an actual space are substantially more difficult than placement tasks, where children put a visible object in a particular location in an actual space. We discuss possible implications of the differential difficulty of retrieval and placement tasks for the understanding of symbolic development.

Keywords: Symbolic development; Spatial models

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1. Introduction

The emergence of symbolic processes in young children is a central issue in the study of cognitive development. Symbolic processes are of critical importance in human communication and thought; they allow people to obtain information about states of affairs in the world that have not been experienced directly. These processes involve mappings of symbols (i.e. maps, models, and words) onto reference fields, capturing information about objects and events. People familiar with the mapping rules can interpret particular symbols, obtaining new information from them. For example, a person who understands a language can learn from verbal directions how to get to the laundromat, and a person who understands how to read a map can learn from it what direction and distance to go to reach that goal.

The present paper concerns children's ability to use spatial symbols such as maps and models to determine the locations of objects. There are various views of the development of spatial symbols, including Piagetian, nativist, and Vygotskyan perspectives (e.g., Gauvain, 1995; Landau, Spelke, & Gleitman, 1984; Liben, 1999; for an overview, see Newcombe & Huttenlocher, 2000). DeLoache and her associates have carried out an extensive set of studies on the earliest development of spatial symbols. In this research children are typically shown an object hidden next to a landmark in a model room, and then they search for that object in the actual room (or vice versa; e.g., DeLoache, 1989, 1995; DeLoache, Kolstad, & Anderson, 1991). To find the object, children must recognize the correspondence between the model and the room, and map a target object from one space to the other. Children can typically do these tasks by about 3 years of age, although there is variation in the age of success due to factors such as the degree of resemblance between the model and the reference space.

In some situations, use of models or maps to locate targets requires more than "representational insight" about object-to-object correspondence (e.g., a whistle hidden under a small cushion on a couch in the model space is under a larger cushion on a real couch in the referent space). In particular, when targets are not adjacent to landmarks but rather are located some distance from them, scaling is required to map corresponding distances between the model or map space and the actual space (Blades & Spencer, 1994). Piaget et al., 1948/1967 believed that scaling requires proportional reasoning, and, since they found that proportional reasoning only arises in late childhood, they argued that the ability to interpret maps would be a late development.

Recent work shows, however, that scaling arises much earlier than Piaget believed. Huttenlocher, Newcombe, and Vasilyeva (1999) found that children could use distance information from a map to determine location along a single dimension in a long narrow sandbox by 4 years of age and could determine location from a more typical map where distance was scaled along two dimensions by 5 years. The ability to do scaling tasks emerged about a year or so later than the ability to do object-to-object correspondence tasks.

In this paper, we address two issues concerning the difficulty of scaling in symbolic spatial tasks. The first issue concerns the relative difficulty of maps and models.

Our earlier work on scaling used maps (Huttenlocher et al., 1999; Vasilyeva & Huttenlocher, 2004). Children's performance might be different with models, but it is not clear how. On the one hand, it might be easier to recognize a correspondence between two situations when they are more similar and models seem more similar to real spaces than maps (Blades & Spencer, 1994; Gentner, 1989; Liben & Yekel, 1996). On the other hand, recognizing a correspondence might instead be more difficult for models than maps because the elements have a "dual nature" (DeLoache, 1991). That is, models are real objects ("things") as well as symbols, whereas maps are not actual objects and hence may more easily be treated as symbols. In our earlier work we examined the developmental trajectory of children's ability to use maps in retrieval tasks; in Experiment 1 here, we examine if the developmental trajectory is different for retrieval tasks with models.

The second issue concerns the nature of the task. Generally, the ability to use spatial symbols has been assessed with *retrieval tasks*, where an object is shown in a map or model and the child must find the object in the reference space. This task seems to capture a critical feature of the ability to use maps or models – namely, the ability to use spatial symbols to locate a hidden target in an actual space. However, sometimes maps or models are used in a different way, with *placement tasks*, where a present object must be placed in an actual space to correspond to its location in a map or model; e.g., using a diagram to locate the dinner plate relative to the knives, forks and spoons for a formal banquet. This task seems to capture the same critical ability as a retrieval task – an ability to use a map or model to locate a target in an actual space.

There is one experiment that used a placement task involving object-to-object correspondence (DeLoache et al., 1991). A picture of a landmark (a chair) was shown with an object on top of it. An object that matched the pictured object except in size was given to the child, who was to place it on an actual chair. Even 24-month-olds could place the object in the reference space, much earlier than they could do a parallel retrieval task. This finding was an incidental one, and a fully developed explanation for the observed difference has not been proposed, nor has the phenomenon been explored systematically in further research.

In Experiment 2, we present children with a placement task that requires distance scaling, allowing us to compare the difficulty of retrieval and placement tasks (Experiment 1 versus Experiment 2). We argue that the difficulty of interpreting symbols on different tasks may depend on what processing steps are required to establish the relation of an object in the symbolic space to the reference space. In the placement task, the target object is present, so it is only necessary to determine the target's location shown in the model. In the retrieval task, on the other hand, the target object is hidden, so two steps are required. The first step is to determine the target's location shown in the model. The second step is to either recover the object or to point to its hiding place; because the object is hidden, representation of the target in memory must be maintained until the response is made.

Experiment 2 was inspired by earlier work with linguistic symbol tasks. Huttenlocher and colleagues (Huttenlocher, Eisenberg, & Strauss, 1968; Huttenlocher & Strauss, 1968) presented 3-year-olds with sentences such as "The red marble is behind the green marble'' together with a board that had a linear array of three holes for placing marbles. There were two conditions. For one condition, both marbles had to be placed in a board. For the other condition, the green marble was in place in the center hole of the same board, and the child had to place the red marble relative to it. Both conditions used the same symbols, and the probability of chance success was equal across conditions. Nevertheless, the condition where both marbles had to be placed was considerably more difficult than the one where one marble was fixed. We argued that the differences in difficulty were due to differences in the number of processing steps required to construct the solution from the starting situation. When the green marble is fixed, only one step is required – placing the red marble. In contrast, when both marbles had to be moved into place, two steps are required – placing the green marble and then placing the red marble relative to it. The ability to interpret spatial symbols also may go through a developmental sequence in which difficulty is determined by the number of steps required.

2. Experiment 1: A retrieval task using a model

This experiment examines children's ability to use a model in a retrieval task involving scaling of distance. In our earlier research with maps, we found that children were successful in a one-dimensional scaling task by 4 years. Here, we present a model task to determine if scaling along a single dimension may emerge at an earlier (or later) age. In addition, this experiment lays the groundwork for comparison of the difficulty of retrieval (Experiment 1) versus placement (Experiment 2) tasks.

2.1. Participants

Three age groups were tested; twenty 3-year-olds (mean age: 36 months, range: 34–38 months), twenty 3.5-year-olds (mean age: 42 months, range: 40–44 months), and twenty 4-year-olds (mean age: 48 months, range: 46–50 months). The number of boys and girls in each age group was approximately equal. A few children were excluded because they did not complete all trials. All participants were recruited through preschools serving middle-class families from diverse ethnic backgrounds.

2.2. Materials

The sandbox was built out of plywood (60 in. long, 15 in. wide, 12 in. deep), with the top 2 in. filled with sand. Small black discs (1 in. in diameter) served as objects to be ''hidden'' in the sandbox. The sandbox was located in the center of the room. Small plywood sandbox models had the same proportions as the large sandbox (8 in. long, 2 in. wide, 1.5 in. deep). They had a false bottom covered with a layer of sand that was glued so it could not be spilled. Models had a single black disc (3/8th in.) attached to the sand in the predetermined locations. Locations differed only along the length of the model. There were ten different models. Seven were used in the experimental trials. Table 1 shows the locations of the discs. Additional

Table 1
Corresponding locations in the sandbox and in the model (in both cases, distance is indicated in inches, counting from the left edge)

True location in the sandbox	7.5	15	22.5	30	37.5	45	52.5
Dot location in the model	1	2	3	4	5	6	7

models were used for demonstration trials: one displayed a disc 2.5 in. from the left edge, and the other 5.5 in. from the left edge.

2.3. Procedure

The experimenter told the child that they were going to play a game with the sandbox. The child was seated in front of the sandbox (about 15 in. from it) near its center and the experimenter sat next to the child. On two practice trials, the experimenter showed the child a model with a disc and said, "*See where the dot is? I hid a big dot in your sandbox and this (pointing to the model) tells you where I hid it. Your job is to go to your big sandbox and find the place where I hid the dot. Just touch the sand where I hid the dot*". The child was told to point to the right spot. When the child pointed to a particular location, the experimenter dug the sand underneath it. If there was a disc underneath, the experimenter praised the child and proceeded. If the child pointed to the incorrect location, and there was no disc within a 5 in. distance from where the child pointed, the experimenter said, "*Uh oh! There's no dot here! Let's look at this little sandbox again. Do you see the dot in the little sandbox (pointing to model)? I think that the hidden dot should be here (pointing to the correct location in the big sandbox). Let's dig up this spot and see if there's a dot!*" In either case, the experimenter emphasized: "*This spot in the big sandbox (pointing to the large disc in the sandbox) is just like this spot in the small sandbox (pointing to the small disc)*".

Children were then given seven experimental trials; these were similar to the practice trials except that the child received no feedback. Prior to each trial, the experimenter asked the child to turn around for 5–10 s so that the experimenter could "hide a new big dot". Then the child was turned back, shown the model and told, "*See this dot in my sandbox? Remember it shows where I hid the big dot in your sandbox. Can you find the place where I hid the dot in your big sandbox?*" The child then pointed to the location in the sandbox, and the experimenter measured and recorded the distance between the left edge of the sandbox and the child's response. The seven models were presented in one of four pre-selected random orders.

2.4. Results

Children's responses were coded in terms of distance from the left side of the sandbox. These responses were compared to "true locations". For example, if a disc in the model were located 2 in. from the left edge, the true location of the disc in the sandbox would be 15 in. from the left edge of the box (scale factor 1:7.5). An analysis

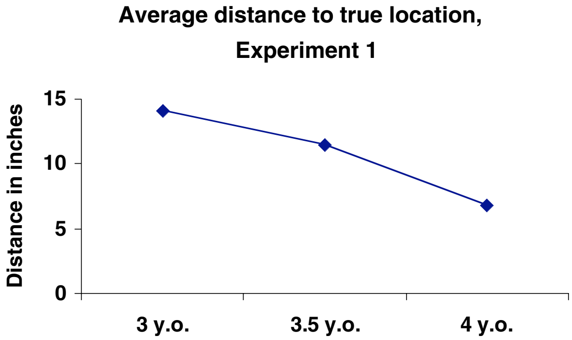

Fig. 1. Average distance to true location, Experiment 1.

of variance was carried out with the average distance between response and true locations as a dependent variable. A 3 (age) by 2 (gender) ANOVA showed that there was no main effect of gender, $F(1,53) = 2.53$, $p = .12$, nor was there a significant interaction between gender and age, $F(2,53) = 1.81$, $p = .17$. The effect of age, on the other hand, was highly significant, $F(2,53) = 11.61$, $p < .0001$. To compare directly the performance of different age groups, we conducted post hoc pairwise comparisons using the least significant difference (LSD) analysis. This analysis revealed that 4-year-old children performed significantly better than both 3-year-olds ($p < .0001$) and 3.5-year-olds ($p = .007$). The difference between 3- and 3.5-year-olds was marginally significant ($p = .06$). Fig. 1 shows this pattern of performance.

Following the analysis of group performance, we analyzed individual response patterns. For each child, we examined whether the order of response locations matched the order of true locations. For example, we tested whether the child's response for the left-most value of the true location (7.5 in.) was to the left of the response for the next value (15 in.), and so on for the entire set of seven responses. The performance of children who largely preserved the ordinal relations among locations (i.e., who had at most one ordering error across all seven trials) was scored as correct. The analysis revealed that none of the 3-year-olds, 35% of 3.5-year-olds and 79% of 4-year-olds preserved the ordinal relations. The responses of children who matched the order of true locations were also close to these locations (average distance between response and true location in this group was 5.2 in.), thus indicating that children preserved both order and distance information. In contrast, for the group of children who did not preserve ordinal relations, the average distance to true location was 14.03 in. The average responses of this group were closer to the center of the box than the corresponding true locations. This is because pointing randomly to different locations across the box resulted in an average near the center.

2.5. Discussion

Success on our spatial model retrieval task emerges at about 4 years of age, the same age as for maps. There is a clear developmental progression with 3-year-olds failing the task, most 4-year-olds succeeding, and 3.5-year-olds showing intermediate performance. Our earlier work showed that the ability to do a corresponding task involving maps also emerged in 4-year-olds, with younger children performing at lower levels on average, i.e., some 3-year-olds performed as well as 4-year-olds while others failed to preserve order (Huttenlocher et al., 1999). It seems that the ability to carry out symbolic retrieval tasks involving scaling along a single dimension emerges at roughly the same age regardless of whether the task involves maps or models.

In most tasks involving scaling, maps have been used. The existing literature suggests alternative possible predictions about the relative difficulty of maps and models. On the one hand, models are generally more similar to their referents than maps, and it has been argued that symbol tasks with greater similarity between symbols and their referents are easier (Blades & Spencer, 1994. Gentner, 1989. Liben and Yekel, 1996). The models in the present study were identical to the reference spaces except for size, whereas the maps in Huttenlocher et al. (1999) were schematic and quite different from their referents. On the other hand, the work of DeLoache (1989, 1991, 1995) suggests that models could be more difficult than maps because of their "dual nature", i.e. the fact that they are objects as well as symbols. Indeed, DeLoache (1991) found that, for tasks where both pictures and models were highly similar to the reference space, pictures were easier than models. The fact that, in the present study, model tasks were similar in difficulty to the map tasks we had used earlier shows either that neither factor is important once children have achieved basic representational insight, or perhaps that the two factors cancel each other out.

Success on tasks that require scaling emerges a whole year later than on object correspondence tasks. Piaget believed that this was because relative extent is a proportional notion that develops late. However, more recent work has shown that relative coding arises early (Bryant, 1974; Huttenlocher, Duffy, & Levine, 2002), and that even infants can match relative quantities (Duffy, Huttenlocher, Levine, & Duffy, 2005). Hence, difficulty with symbolic scaling tasks is *not* due to an inability to code relative quantity. Why then are symbolic tasks involving scaling more difficult? The reason may derive from the fact that object-to-object correspondence involves only mapping of object properties whereas distance-to-distance correspondence involves the mapping of distances defined by endpoints, in our study, the object's location and an end of the box.

3. Experiment 2: A placement task

Experiment 2 examines whether symbolic spatial tasks involving placement can be done at an earlier age than tasks involving retrieval. In particular, we examine the difficulty of tasks involving spatial symbols to determine object location from a model under two different conditions. In both conditions, the model is a long, narrow box, and the child must use that model to indicate the location of an object in a larger space of the same shape. In one condition the model is used to retrieve a hidden object from a particular position in the reference space. In the other condition the model is used to place a visible object in a particular position in the reference space. In both conditions, children must scale the distance shown in the model to determine the location of an item in the actual space.

3.1. Participants

Three age groups were tested. These included twenty 3-year-olds (mean age: 36 months, range: 34–38 months), twenty 3.5-year-olds (mean age: 42 months, range: 40–44 months), and twenty 4-year-olds (mean age: 48 months, range: 46–50 months). There was an approximately equal number of boys and girls in each age group. Several additional children (2 in the 3-year-old group and 2 in the 3.5-year-old group) were excluded from the final analysis because they did not complete all experimental trials. The participants were recruited from the same pool of children as those in Experiment l.

3.2. Materials

The materials used in Experiment 2 were the same as those in Experiment 1.

3.3. Procedure

As in Experiment 1, the experimenter told the child that they were going to play a game with the sandbox. The child sat in front of the sandbox (about 15 in. from it) near its center and the experimenter sat next to the child. As in Experiment 1, there were two practice trials and seven test trials.

On each practice trial, the experimenter showed the child a model with a disc and said, "*See where the dot is? You need to make your sandbox look like mine. Your job is to take this big dot (handing the child the disc) and put it in your big sandbox so that it looks like mine*". If the disc was placed within 5 in. of the correct location, the experimenter praised the child and proceeded. Otherwise, the experimenter moved the disc. In either case, the experimenter emphasized: "*This spot in the big sandbox (pointing to the disc) is just like this spot in the small sandbox (pointing to the small disc)*".

Experimental trials were similar to the practice trials except that the child did not receive feedback. Prior to each experimental trial, the child was turned by 180° for 5–10 s so that the experimenter could smooth over the sand. Then the child was turned back, handed the model and told, "*See this dot in my sandbox? Remember you have to make your sandbox look like mine. Can you put the big dot in your sandbox to make it look like mine?*" The experimenter measured the distance between the left edge of the sandbox and the child's response and recorded it. The seven models were presented in one of four pre-selected random orders.

3.4. Results

Children's responses were coded as in Experiment 1. For each response we calculated the distance between response and true locations. An analysis of variance was

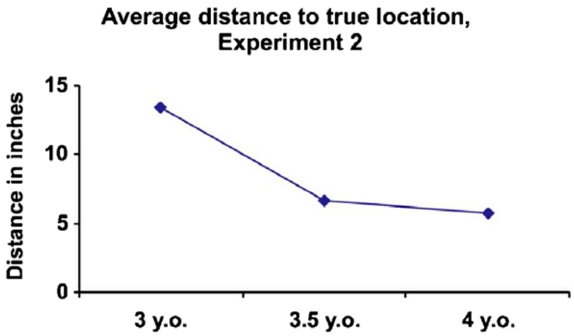

Fig. 2. Average distance to true location, Experiment 2.

carried out with the average distance between response and true locations as the dependent variable and with age and gender as independent variables. Similar to Experiment 1, the ANOVA showed that there was no effect of gender, $F(1,53) = 3.2$, $p = .08$, nor was there an interaction between gender and age, $F(2,53) = .52$, $p = .6$. Again, the effect of age was highly significant, $F(2,53) = 20.00$, $p < .0001$. However, pairwise comparisons between the three age groups revealed a different pattern of performance as a function of age than that in Experiment 1. The LSD procedure showed that 3-year-olds performed significantly worse than both 3.5- and 4-year-olds (in both cases, $p < .0001$). Unlike in Experiment 1, 3.5-year-olds did not perform differently than 4-year-olds ($p = .52$). This pattern is illustrated in Fig. 2.

Following the analysis of group performance, we analyzed individual performance using the same ordering criterion as in the previous experiment. That is, the performance of children who had at most one ordering error across all trials was judged as correct, otherwise performance was judged as incorrect. According to this criterion, 20% of 3-year-olds, 80% of 3.5-year-olds and 80% of 4-year-olds were correct. Not only did these children preserve the ordinal relations among locations, they also preserved distance information by placing their responses near the true locations (average distance 4.97 in.). In contrast, for the group of children who did not preserve ordinal relations, the average distance between response and true locations was 14.07 in. As in the previous experiment, these children pointed randomly to different locations across the box, disregarding the location of the dot on the map.

3.5. Comparison of performance in Experiment 1 and Experiment 2

As shown in Fig. 3, the performance of different age groups on model tasks differs for the retrieval task (Experiment 1) versus the placement task (Experiment 2). In the retrieval procedure, all 3-year-olds failed the task, most 4-year-olds succeeded on the task, and the majority of 3.5-year-olds performed like the 3-year-olds. In contrast, in the placement procedure, 3.5-year-olds performed similarly to 4-year-old children, successfully translating distance information from the model to the sandbox.

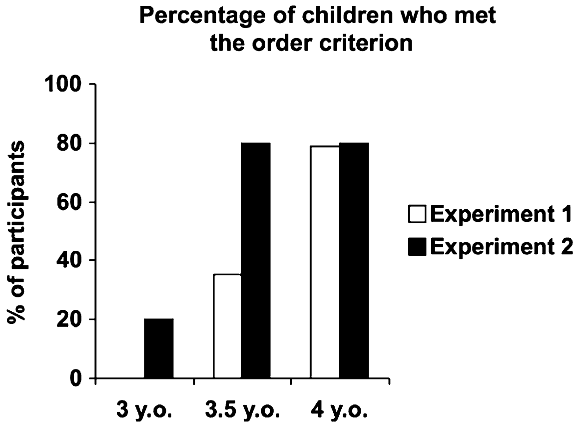

Fig. 3. Percentage of children who met the order criterion.

We carried out a statistical analysis to compare the accuracy of performance by different age groups in the two experiments. In this analysis, we used the average distance between response and true location as the dependent variable. A 3 (age) by 2 (gender) by 2 (experiment) ANOVA revealed a significant main effect of age, $F(2, 108) = 33.44$, $p < .0001$, and a marginal effect of experiment, $F(1, 108) = 3.42$, $p = .07$. Our further analysis indicated that this marginal effect of experiment was driven primarily by a single age group, namely, by 3.5-year-olds. Indeed, there was a significant interaction between age and experiment, $F(2, 108) = 3.87$, $p < .05$. Follow-up tests (LSD pair-wise comparisons) showed that the performance of 3-year-olds did not differ in between the two experiments, and neither did the performance of 4-year-olds (both p's $>.05$). In contrast, 3.5-year-olds showed a significant difference between Experiment 1 and Experiment 2, $p < .05$.

3.6. Discussion

We found that children were successful on a placement task six months earlier, on average, than on a comparable retrieval task. It might be argued that the retrieval task was harder than the placement task because of general motivational factors, such as children finding it less interesting to search for hidden objects than to place visible ones, especially since they do not get to retrieve the object. However, on non-symbolic tasks, when children simply observe an object being hidden in a similar long thin sandbox and then point at it after a short delay, they succeed at ages as young as 16 months (Huttenlocher, Newcombe, & Sandberg, 1994). In such earlier studies, we have consistently found that children succeed (and enjoy), indicating the locations of hidden objects even on tasks where they typically point to the location rather than retrieve it. Thus, this experiment confirms the serendipitous result in an earlier study by DeLoache et al. (1991) that placement is easier than retrieval, extending it from tasks involving object-to-object correspondence to tasks requiring scaling of distance.

4. General discussion

Our findings indicate that model and map problems are similar in difficulty in these tasks which involve scaling. However, retrieval tasks are not more difficult than placement tasks. As we have noted, current conceptualizations of symbolic development would not predict that these tasks would differ in difficulty. The symbols in retrieval and placement tasks are the same, the reference space is the same, and the probability of chance success also is the same. Yet our findings clearly indicate that retrieval is more difficult than placement. We have suggested that the difference in task difficulty can be thought of in terms of the steps required to interpret the symbols in particular tasks. For the placement task, the child must place a present object in an actual space, using the model to indicate the location of this object. In contrast, for the retrieval task, the child must point to a hidden object in an actual space, using the model both to establish the existence of the hidden object and to indicate its location.

This analysis suggests a different way to think of the development of the ability to succeed on spatial symbol tasks, intermediate between two opposing extreme positions. At one extreme, it might be argued that children possess the underlying symbolic competence to do both tasks from the start. Their failure on the retrieval task would simply reflect performance factors. However, arguments of this kind involve constructing increasingly simple forms of a task, ultimately stripping away much of what is involved in real-world problems. At that point, postulating symbolic competence often seems problematic. At the other extreme, it might be argued that neither of these tasks requires symbolic competence. Indeed, Brooks (1991) and Warren (2005), among others, argue that behaviors that seem to involve complex internal processes such as symbol interpretation often can be explained, instead, by the same principles that explain simple behaviors. If this were correct, tasks that investigators group together as "symbolic" actually would be guided by separate skills rather than drawing on a general symbolic competence. However, the tasks share a formal similarity, and this argument ignores the possibility of an emerging common set of processes (Huttenlocher, 2005).

An intermediate possibility is that the emergence of symbolic skills is a sequenced process that begins from starting points that do not themselves constitute mature skill. This sequenced process is guided by definable principles that culminate in a set of skills that together constitute a general spatial symbolic competence. This paper represents an initial attempt at delineating such a developmental sequence from the spatial strengths of infancy to the symbolic capacities of the school-entry child.

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