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FAST-TRACK REPORT

Young children's spontaneous use of geometry in maps

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Abstract

Two experiments tested whether 4-year-old children extract and use geometric information in simple maps without task instruction or feedback. Children saw maps depicting an arrangement of three containers and were asked to place an object into a container designated on the map. In Experiment 1, one of the three locations on the map and the array was distinct and therefore served as a landmark; in Experiment 2, only angle, distance and sense information specified the target container. Children in both experiments used information for distance and angle, but not sense, showing signature error patterns found in adults. Children thus show early, spontaneously developing abilities to detect geometric correspondences between three-dimensional layouts and two-dimensional maps, and they use these correspondences to guide navigation. These findings begin to chart the nature and limits of the use of core geometry in a uniquely human, symbolic task.

Introduction

Humans often are characterized as the 'symbolic species' because of our capacities to learn and use a rich array of symbol systems, including natural language, pictures and signs (Deacon, 1997; DeLoache, 1995; Goodman, 1976). Geometric maps are a particularly useful system for representing, communicating about, and guiding navigation through the surrounding environment (Newcombe & Huttenlocher, 2000; Uttal, 2000; Gentner & Rattermann, 1991). All mobile animals represent the surrounding space for purposes of navigation, but only humans supplement their mental representations by creating and using external maps.

Recent research suggests that map understanding is universal across humans (Dehaene, Izard, Pica & Spelke, 2006; see also Newcombe & Uttal, 2006). Adults and 6- to 10-year-old children in an urban US community and in a remote Amazonian indigenous group were presented with an arrangement of three containers in a large, navigable space, and with a two-dimensional paper map of the arrangement. While participants viewed the map with their backs to the containers, a single location was indicated on the map, corresponding to the location of a hidden object. Their task was to find the hidden object in the correct container, based on the location indicated on the map. Although the US adults performed better than the other three groups, adults and children in both societies performed well above chance and showed the same characteristic error patterns. First, they performed better when the object was hidden at a landmark, whose distinctive color and outline shape were indicated on the map. Second, participants showed greater sensitivity to Euclidean *distance/angle* than to *sense*.[1] Third, participants showed greater sensitivity to geometry when no distinctive landmarks were present than when one such landmark was present. The findings were taken to provide preliminary evidence for a system of core knowledge of geometry, common to people with widely divergent experiences.

As critics of this research pointed out, the development of this system of knowledge remains largely unknown (Newcombe & Uttal, 2006). Because the participants were at least 6 years old, and because they all lived in cultures providing exposure to geometric patterns, it is not clear when or how the capacity to use maps emerges. Moreover, each trial of the above experiment provided informative feedback to the participants, and trials with landmarks always preceded trials without landmarks. It is not clear, therefore, whether humans lacking map experience can use geometric information in maps in the absence of feedback, and whether they do so more effectively in the absence of distinctive landmarks.

Recent studies of animals reared in controlled environments provide evidence that sensitivity to distance and sense relationships in the surrounding spatial layout emerges without prior exposure to a geometrically structured layout (Chiandetti & Vallortigara, 2008), although the salience of these relationships, relative to non-geometric color cues, is enhanced by such experience (Brown, Spetch & Hurd, 2007; see also Gray, Bloomfield, Ferrey, Spetch & Sturdy, 2005). Such animals do not use maps,

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[1] Because the experiment used only triangular configurations, distance and angle were confounded in this task.

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however, so these experiments do not shed light on the origins and development of human understanding of spatial symbols. Research with younger children provides the best means to address this question.

Past research provides mixed evidence concerning young children's ability to extract and use geometric information in maps. In one set of studies, 4- to 5-year-old children were given maps of landmarks within their classroom. After some training, children successfully used the featural information in the maps as direct cues to landmarks, but they failed to use geometric relationships among objects to specify such locations (Liben & Yekel, 1996). In other studies, 3- to 4-year-old children were presented with simpler maps lacking featural information and indicating only the geometric properties of the array. After brief training, children successfully used the maps to specify target locations, both when the orientations of the map and the layout were aligned (Huttenlocher, Newcombe & Vasilyeva, 1999; Vasilyeva & Huttenlocher, 2004) and when they were not (Vasilyeva & Bowers, 2006). The contrasting findings in landmark-rich and landmark-free environments raise the possibility that landmarks diminish sensitivity to geometric information for children, as they may for adults (Dehaene *et al.*, 2006). However, the tasks used in these studies differed in many ways, and no previous studies of map-reading have systematically varied landmark cues. Furthermore, no past experiment, to our knowledge, has investigated whether young children use geometric information in maps without training or feedback on the task.

The present experiments addressed these questions. In two experiments, we presented preschool children with a variation of the map task of Dehaene *et al.* (2006). Because past research has suggested that understanding maps as representations of the environment emerges at about 4 years of age (e.g. Bluestein & Acredolo, 1979; Vasilyeva & Bowers, 2006), 4-year-old children were tested. To investigate children's spontaneous use of distance, angle and sense information, the task used linear as well as triangular arrays and involved no mention of geometry or training on the use of geometric information. We used a placement task rather than a finding task, both because placement tasks are easier for children at this age (Huttenlocher, Vasilyeva, Newcombe & Duffy, in press) and because they allowed us to provide neutral, uninformative feedback on children's performance. We asked: (a) if preschool children spontaneously detect and use the correspondence between geometric relationships in a simple map and in a layout of objects, (b) if they show the same signature error patterns found in past research with older children, and (c) if they show enhanced attention to geometry under conditions where no landmark is present.

Experiment 1

Experiment 1 investigated young children's spontaneous use of simple maps of three-object arrays. On each trial, children placed a toy in one of three containers arranged in a line or triangle, after the correct container was indicated on a map. The map consisted of three forms, arranged to preserve the containers' distance, angle, and sense relations, but differing from the corresponding array in dimensionality (2D rather than 3D), size (about 12 times smaller), and orientation (variable across trials). Two of the containers and corresponding forms were identical; the third container and corresponding form were distinctive and served as a landmark. On each trial, the experimenter arranged the containers behind the child's back, presented a map, indicated the target location on the map, and then encouraged the child to place an object at that location in the 3D array.

Method

This method followed that of Dehaene *et al.* (2006), with five changes. First, children were tested individually in the laboratory or in an empty classroom, observed only by the experimenter and by a parent or teacher. Second, a placement task was used, providing no informative feedback across trials. Third, trial order was counterbalanced. Fourth, the experiment included trials with objects in a linear arrangement, as well as the triangular arrangements previously tested. Finally, to shorten the testing session for 4-year-old children, we divided the original task into two experiments.

Participants

Seven boys and 11 girls (M_{age} = 50.6 months, range 41–62 months) were tested at a local daycare center (n = 14) or at the Laboratory for Developmental Studies at Harvard University (n = 4). All participants received a small toy for their participation, and those who traveled to the lab received a $5 travel reimbursement.

Materials

Children viewed 18 laminated maps printed on 21 cm × 28 cm paper. Each map depicted three shapes (two gray circles and a red square), one of which was starred. The shapes were arranged in an isosceles triangle, a right triangle, or a straight line. Three objects (two gray buckets and a red box, about 20 cm tall and 20 cm wide) were arranged on the floor about 2 meters away, with the 28 cm side of the map scaling up to 3 meters of space (Figure 1). Small toys served as the objects to be placed.

Design

Maps were presented in six blocks of three trials each. Each block included a single array type (isosceles, right, straight) presented at a single orientation (egocentric or allocentric relation between map and world), and each of the three target locations. The order of target locations,

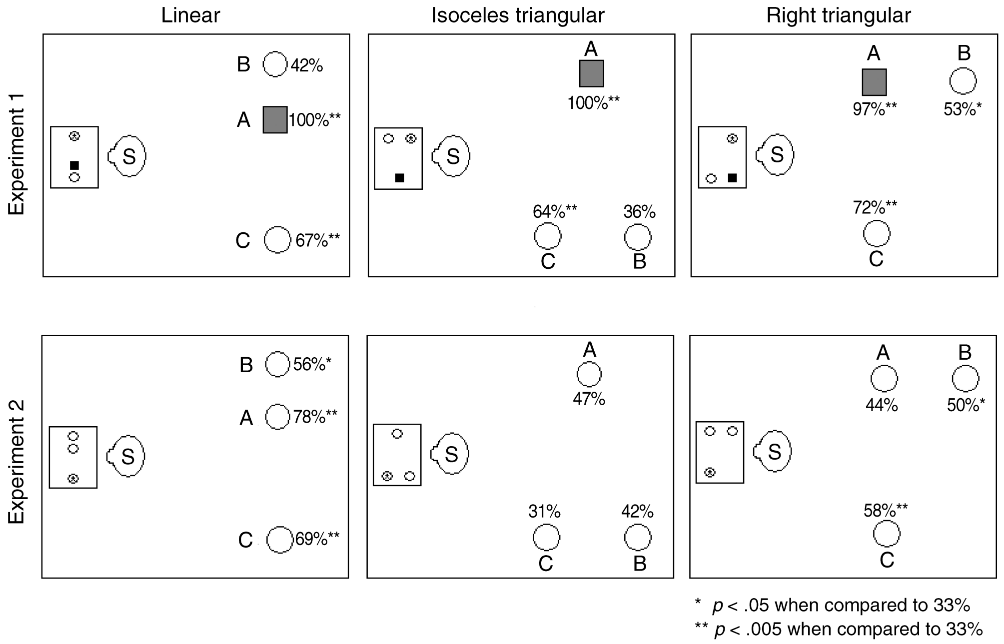

Figure 1 *A diagram of the experimental room, indicating the map, the child (S), and the array consisting of three containers, A, B, and C. Although both map orientations (allocentric and egocentric) were used in each experiment, the egocentric orientation is depicted for Experiment 1 and the allocentric for Experiment 2. Percent accuracy, collapsed across both orientations, is shown for each location and compared to a chance level of 33%.*

array types, and orientation was fully counterbalanced within and across subjects using a Latin-squares design.

Procedure

The experimenter introduced children to the map game with three warm-up trials. In the first trial, only the red box was present in the room, and a single starred red square was shown on the map. Children were instructed to stand squarely in front of the maps with their backs to the array, and to point manually to the star on each trial before placing Froggy in one of the containers. The experimenter said, 'This picture tells us where Froggy wants to sit. Froggy wants to sit where the star is. Can you point to the star? Great, can you put Froggy where he wants to go?' Children were encouraged to place Froggy in the red box on the floor if they did not do so spontaneously. Either the child or the experimenter retrieved Froggy for the next trial. The second and third practice trials used the red box and one gray bucket. Children received one practice trial with each location as a target. Because no practice trial involved more than two objects, geometric information was not available to specify the object's correct location. Children then received the full set of 18 three-object maps using the same procedure.

Analyses

Overall percentage of correct placement of the toy was compared to chance (33%). Effects of orientation (egocentric, allocentric), array (isosceles, right, linear), and hiding location (A, B, C) were analyzed using ANOVAs. To assess landmark use, we compared success on trials with hiding locations at the landmark (A) to success on trials at locations B and C. To assess sensitivity to geometry (distance, angle, or sense in different conditions), we computed the percentage of correct placement at B or C out of total searches at B or C on trials for which one of those locations was correct, and compared this proportion to chance (50%).

Results

Figure 1 presents children's performance on each type of trial. Overall, children performed well above chance on this task (mean 70% correct, compared to 33% chance, $t(17) = 16.46$, $p < .0001$). A preliminary analysis revealed no effects of map orientation (70% correct at each orientation, $t(17) = .08$, *ns*), so subsequent analyses collapsed across this variable.

Children performed more accurately when the indicated location was the unique landmark than when it was one of the other two locations, 99% vs. 56% correct, $t(17) = 11.151$, $p < .0001$. On non-landmark trials, children selected a non-landmark container 99% of the time, compared with 66% chance, $t(17) = 32.3$, $p < .0001$.

Children's use of geometry, defined as the ability to select between the two non-landmark locations, was only marginally above 50% chance: 56% correct, $t(17) = 1.83$, $p < .09$ (Figure 2). Geometric performance was above chance for the right triangular array, 63% correct, $t(17) = 2.20$, $p < .05$, but not for the isosceles array, 50%, $t(17) = 0$, *ns*, nor the linear array, 56%, $t(17) = 1.18$, *ns*. Children showed higher sensitivity to geometry in the

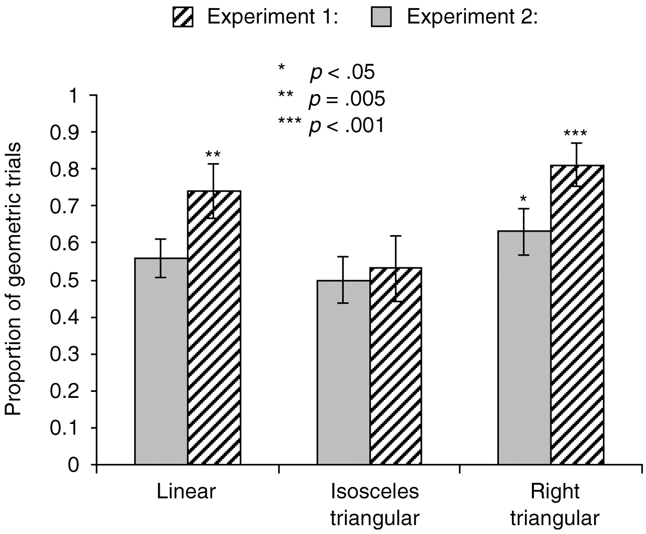

Figure 2 *Correct use of geometry for each type of array (Linear, Isosceles Triangular, Right Triangular), with a landmark (Experiment 1) and with no landmark (Experiment 2). Proportion of geometric trials was defined as the total correct selection of locations B and C (the two non-landmark containers in Experiment 1), out of total searches at either B or C on trials where either B or C was the target.* P-*values are indicated for comparisons against chance rates of .50.*

right triangular array than in the isosceles triangular array, $t(17) = 2.20$, $p < .05$, providing evidence for use of distance and/or angle relations. Use of geometry in the linear array was intermediate between, and not significantly different from, use of geometry in the other arrays, each $t(17) < 1$, *ns*.

Discussion

In this experiment, preschool children showed two distinctive abilities in their map use. First, they showed highly consistent use of the landmark as a direct cue to the object's location. After minimal training, children consistently chose the distinctive container when it was the correct location indicated on the map, and they avoided that container when it was not, replicating numerous experiments providing evidence for children's use of landmarks in maps (Bluestein & Acredolo, 1979; Liben & Yekel, 1996; Dalke, 1998). Second, children showed reliable use of distance or angle to distinguish between the two identical containers in the array. Although children failed to distinguish between unmarked locations on the sole basis of distance information (in the linear array) or sense information (in the isosceles array), they successfully used distance and angle together to choose between the two unmarked objects in the right triangular array.

Although children's use of geometry was limited, it is striking because the task involved no training of attention to geometry and no feedback concerning its use. These findings, therefore, provide the first suggestive evidence that some metric properties of the environment are encoded and used spontaneously by preschool children in a symbolic task.

A comparison of the results of the present experiment to those of Dehaene *et al.* (2006) reveals several converging patterns of map use by young children and adults. Both studies found higher accuracy when the target location was the landmark object itself. When the target location was one of the two featurally identical objects, participants in both experiments avoided the unique landmark. Nevertheless, one clear difference between the studies emerged: Dehaene *et al.* (2006) found no differences in performance between the two triangular arrays, whereas the present experiment revealed an advantage for the right triangular over the isosceles array.

Children's use of geometry on the right triangle array could be explained in two different ways. First, children may abstract geometry relative to the landmark. For example, when children were asked to place an object at one of two identical containers forming the right triangle, they may have chosen the corner at the appropriate distance and angle from the landmark box. Alternatively, children may abstract geometric relations irrespective of the landmark. The findings of Dehaene *et al.* (2006) and of past studies of children's map use (e.g. Liben & Yekel, 1996; Vasilyeva & Bowers, 2006) cast doubt on the first possibility and suggest that landmark representations and geometric representations compete with each other. As we noted, however, this possibility has not been tested directly in experiments that equate for other stimulus and task effects.

The next experiment was undertaken for this purpose.

Experiment 2

Experiment 2 tested 4-year-old children's map use with a purely geometric map devoid of landmarks. A new group of children was tested by the same method as Experiment 1: a placement task involving no feedback and preceded by practice trials involving no informative geometry. In contrast to Experiment 1, the three containers in the array and three forms on the map were identical and therefore could be distinguished only by their distance, angle, or sense relations. If children encode geometry only in relation to landmarks, then they should fail to place objects correctly in this task. If children are equally sensitive to geometry regardless of landmarks, then performance in Experiment 2 should resemble that of Experiment 1. Finally, if geometric and landmark representations compete for children's ability to use maps, then children may show more consistent use of distance, angle, or sense in Experiment 2, because no distinctive landmark is present.

Method

The method was the same as in Experiment 1, except as follows. Eight boys and 10 girls (M_{age} = 50.4 months, range 48–55 months) were tested in the laboratory. As in Experiment 1, the three warm-up trials used one red box (Trial 1) or one red box and one gray bucket (Trials 2 and 3); therefore, the practice trials were not informative about the geometric relations relating the map to the array. All subsequent maps in Experiment 2 depicted three identical gray circles, and all arrays presented three identical gray buckets.

Results

Figure 1 presents children's performance on each type of trial. Overall, children performed above chance on this task, 53% correct, compared with 33% chance, $t(17) = 4.95$, $p = .0001$. A preliminary analysis revealed no effects of map orientation (48% allocentric vs. 58% egocentric, paired-samples $t(17) = 1.444$, *ns*), so subsequent analyses collapsed across this variable.

Children performed reliably above 33% chance on the linear array (68% correct, $t(17) = 5.54$, $p < .001$), and the right triangular array (51% correct, $t(17) = 6.29$, $p < .001$), but not on the isosceles triangular array (40% correct, $t < 1$, *ns*). Performance on the three types of arrays differed reliably, $F(2, 16) = 5.28$, $p < .02$. Post-hoc *t*-tests revealed significantly better performance on the linear than on the right triangular array, $t(17) = 2.53$, $p < .05$, or the isosceles triangular array, $t(17) = 3.26$, $p < .01$, and no difference between the two triangular arrays, $t(17) = 1.56$, *ns*.

To test for sensitivity to distance, we analyzed children's accuracy on trials where the target location was the most distant object. Across the three arrays, children successfully selected the distant object 58% of the time, compared with 33% chance, $t(17) = 4.53$, $p < .001$. When the target location was at one of the two objects closest to each other, children avoided the more distant object (80% choice of a closer object, compared with 66% chance, $t(17) = 4.49$, $p < .001$), indicating sensitivity to distance information.

A final set of analyses directly compared performance in Experiment 2 to that of Experiment 1. The presence of a distinctive landmark in Experiment 1 yielded superior performance overall when trials at the landmark itself or its analog were included in the analysis, 70% vs. 53% correct, $t(34) = 3.77$, $p = .001$. A further analysis tested how the presence of the landmark affected children's sensitivity to geometry, focusing only on correct placement at the two locations equivalent to the non-landmark locations in Experiment 1 (i.e. locations B and C). As in Experiment 1, a geometry score was computed for each child as the proportion correct placement at B or C, removing those trials where the child went to location A, the analog of the landmark. Overall, children used geometric relationships more often in non-landmark trials than in landmark trials (68% vs. 56%, $t(34) = 2.30$, $p < .05$; Figure 2). This effect was observed on trials with the right triangular array, 81% vs. 63%, $t(34) = 2.12$, $p < .05$, and marginally on trials with the linear array, 74% vs. 56%, $t(34) = 1.96$, $p = .06$, but not on trials with the isosceles triangular array where performance was at chance in both experiments (53% vs. 50%, $t(34) < 1$, *ns*). The presence of a landmark therefore diminished children's sensitivity to the distance and/or angular relationships among the objects.

Discussion

In Experiment 2, children spontaneously detected the geometric correspondences between simple 2D maps and 3D object arrays. Children showed more sensitivity to geometry in the absence of a landmark, in Experiment 2, than in the presence of a landmark, in Experiment 1. These findings provide evidence that preschool children spontaneously access and use geometric relations between objects in a map task, with no prior training and with no feedback. The findings converge with and extend the findings of Dehaene *et al.* (2006), revealing map-using abilities in a population with little experience of maps.

The results shed light on the geometric relations that children can extract from a map. First, children represented and used the distances between two objects, consistent with previous findings from other tasks (Huttenlocher *et al.*, 1999). Children reliably selected the most distant object of the set of three identical objects, even when the objects were arranged in a line and therefore could not be distinguished by their angular relationships. Children also used distance and/or angle on trials with the right triangular arrays, although we do not know whether children were relying on one or both of these cues because they are correlated in triangular arrays. In contrast, children showed no use of sense relations in the isosceles triangular array. Children's failure to use sense information replicates Experiment 1 and contrasts with the findings of Dehaene *et al.* (2006) with adults and older children. It is not clear whether the higher sensitivity to sense information in those studies stems from the older age of the participants or the presence of feedback in Dehaene's retrieval task.

The comparison between Experiments 1 and 2 provides further evidence for children's use of landmarks. Performance was higher overall when a distinctive landmark was present in the array and indicated on the map. Children used the distinctive landmark in Experiment 1 when asked to place an object there and avoided that landmark when asked to place an object elsewhere. While the landmark benefited overall performance, it competed with geometric cues. Children showed greater sensitivity to distance and angle when they were tested without a distinctive landmark (Experiment 2) than when they were tested with the landmark (Experiment 1). These findings replicate Dehaene *et al.* (2006), in a design that compares the effects of landmarks independent of feedback and practice. They accord with past findings that young children can perform well on tasks involving purely geometric maps (e.g. Vasilyeva & Bowers, 2006) but less well on tasks involving multiple distinctive landmarks (e.g. Liben & Yekel, 1996).

General discussion

Two experiments provide evidence that preschool children spontaneously use geometric information in maps. In a task requiring children to place an object into a container corresponding to a marked location on a simple three-object map, 4-year-old children selected the correct container. This was especially the case when all three containers were identical (Experiment 2) and distinguishable by their distance and angular relations (in the linear and right triangular arrays). Because this task was a placement task rather than a finding task, children's success did not depend on feedback over multiple trials.[2] Furthermore, because practice trials were limited to one- and two-object maps with no informative geometric relationships, children used the geometric cues in the absence of any task instruction. To our knowledge, this is the first study demonstrating young children's spontaneous use of geometric relations in maps.

The present studies help clarify the kinds of information encoded and used most readily by children. First, landmarks reliably guided children's map-based navigation, but only as direct cues to an object's location. Although children, in principle, could use the relative spatial position between the landmark and one of the identical containers, children did not exploit this additional information – they performed no better at those containers when a landmark was present than when it was absent.

Second, children spontaneously encoded and used distance information in the map task, succeeding at linear arrays in which only relative distances specified the target. In contrast, children showed no sensitivity to sense information, as they failed to distinguish between the two symmetrical locations in the isosceles triangular arrays. Although children succeeded in the right triangular arrays, their use of angle information cannot be determined with the present method, as distance and angle are correlated in all triangular arrays (see also Uttal, 1996). The primacy of landmarks as direct cues, and the relative ordering of distance, angle and sense information, accord with past findings from studies of adults and older children (Dehaene *et al.*, 2006).

Finally, our experiments provide evidence that landmark and geometric representations compete with one another in map tasks. Children showed less consistent use of geometry when a landmark was present (Experiment 1) than when it was not (Experiment 2). These findings replicate those of Dehaene *et al.* (2006), in a counterbalanced design without feedback. Thus, sensitivity to geometry is greatest when landmarks are not available.

These studies reveal that symbolic map use emerges early in development, but they do not shed light on the causes of its development. We suspect that children at this age have not been taught to use maps to guide navigation, but two kinds of experience may foster the development of map use in young children. First, young children are immersed in natural language, a symbol system *par excellence*. Although language was not used in these tasks to describe or call attention to relevant geometric relations in the maps, the experimenter did refer to objects while pointing to the map, and her use of language may have cued children to the maps' symbolic function (Newcombe & Uttal, 2006). Second, children are bathed in visual representations such as pictures (DeLoache, 1995), raising the possibility that they received prior informal training in interpreting visual symbols. Future studies could focus on the role, if any, of these experiences in the development of map understanding.

Most importantly, the present findings provide evidence that children spontaneously access and use knowledge of geometry in a novel symbolic task. Recent research provides evidence that preschool children similarly harness their pre-existing, non-symbolic representations of number to make sense of new tasks of symbolic arithmetic (Gilmore, McCarthy & Spelke, 2007). Together, these findings suggest that culture-specific, uniquely human skills are supported by early-developing systems of representation that are universal across cultures. Instruction in the use of maps, graphs, and other visual symbols may be enhanced by teaching strategies that build on children's spontaneously developing symbolic abilities.

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[2] Accordingly, we found no change in performance between the first and last three trials (for Experiment 1, mean 76% vs. 65% correct, respectively, $t(17) = 1.24$, *ns*; for Experiment 2 mean 52% correct for both blocks, $t(17) = 0$).

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