The Road to Understanding Maps

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ABSTRACT—Children and even some adults struggle to understand and use maps. In the symbolic realm, users must appreciate that the marks on a surface stand for environments and must understand how to interpret individual symbols. In the spatial realm, users must understand how representational space is used to depict environmental space. To do so, they must understand the consequences of cartographic decisions about the map's viewing distance, viewing angle, viewing azimuth, and geometric projection. Research identifies age-linked progressions in symbolic and spatial map understanding that are linked to normative representational and spatial development, and reveals striking individual differences. Current work focuses on identifying experiences associated with better map understanding. New technologies for acquiring, manipulating, analyzing, and displaying geo-referenced data challenge users and researchers alike.

KEYWORDS—maps; symbols; spatial cognition; representation; development

Children are often the butt of jokes about map understanding. In one cartoon, for example, Dennis the Menace and his dad, Hank, are examining a map. Dennis asks how long the trip will take, and Hank replies that it will be about two days. Incredulous, Dennis responds, "*Two days*? Just to go *three inches*?" Dennis is confused by map scale, expecting paper space to translate more directly to environmental space. In another cartoon, Pasquale of *Rose is Rose* is riding in the family car. Agitated, he calls out to his parents, "Ona rong road!" From following the trip on a road map, he knows the road they want is red, not grey. Pasquale is confused by map symbols, expecting that the color of the line (symbol) necessarily reveals something about the color of the road (referent). Adults, too, may have difficulty: A newspaper reports that a logger defended himself for cutting down his neighbor's trees because his map was “turned the wrong way” (Liben, Kastens, & Stevenson, 2002); researchers find that college students make dramatic errors in showing their locations on a campus map (Liben, Myers, & Kastens, 2008). And, apart from cartoons, newspapers, and research, most readers undoubtedly know (or count themselves among) people befuddled by maps.

People are not born knowing how to read maps any more than they are born knowing how to read words. What are the components of map understanding? What are the basic cognitive foundations on which that understanding rests? How early and universally does understanding begin to emerge? What leads some people to interpret maps easily while others struggle? Can those who struggle be taught to improve? In collaborative work involving developmental psychologists, cognitive psychologists, geographers, geoscientists, and educators, we address these and related questions. Here I review children's developing understanding of the fundamental symbolic and spatial meaning of maps. Findings also illustrate how approaches drawn from developmental work may be helpful in identifying and clarifying individual differences in adults' map understanding.

MAPS IN THE HEAD AND MAPS IN THE HAND

Much psychological research has focused on cognitive maps, which are studied to learn how environmental knowledge is accumulated and integrated. Here instead the focus is on “real” maps—external, physical artifacts that represent some portion of the world—studied to identify processes entailed when graphic representations are used to acquire, record, communicate about, or reason with symbolic and spatial information.

The Symbolic Nature of Maps

Maps are representational, not in the sense of *re*-presenting or re-producing, but rather in the sense of meaning making or symbolizing (Liben, 2001). Map users must thus appreciate maps’ overall meaning in a holistic fashion. Research on children’s interpretation of scale models demonstrates that 3-year-olds understand that one thing can stand for another (DeLoache, 1987). Thus, not surprisingly, map research (Liben & Downs, 1989) shows that preschoolers typically interpret maps and aerial photographs as places (e.g., “States and stuff,” “Buildings and roads”), albeit often misjudging scope (e.g., interpreting an aerial photograph of Chicago as “the whole world” and a Pennsylvania road map as “California, Canada, the West, and the North Coast”).

Map users must also interpret individual map symbols. This componential understanding requires knowing that symbols not only represent but, simultaneously, have qualities of their own (duality) and that qualities of symbols may—or may not—resemble qualities of their referents (iconic vs. arbitrary symbols respectively). Consistent with cognitive-developmental theories holding that children only gradually come to differentiate symbols from their referents (Vygotsky, 1934/1962), map research shows that before the middle primary grades, children often conflate symbolic and referential qualities. For example, Liben and Downs (1989) reported that preschoolers inferred that red lines indicated red roads, the round shape on Lake Erie (a compass rose) showed a “basketball,” and yellow areas (cities) showed “eggs.” Iconicity errors are rare among older children: In a field-mapping task with 10-year-olds, only a few responses implied unjustified assumptions about color or shape iconicity (Kastens & Liben, 2007).

A developing understanding of symbol creators' intentions also contributes to children's growing success in disentangling symbolic and referential qualities. In two studies (Myers & Liben, 2008), children watched adults place dots on room maps. One adult portrayed symbolic intent by adding green dots to the paper to record where someone was hiding objects in the room. The second portrayed nonsymbolic (aesthetic) intent by adding red dots to make the paper more colorful. Children were asked to describe the actors’ behaviors and to select which map would help them find hidden firetrucks. In Study 1, most 5- and 6-year-olds correctly described the actors’ behaviors but selected the wrong map, justifying their choices by resemblance ("the dots are red like the firetrucks") rather than by actors’ portrayed intentions. In Study 2, children were asked about either hidden red firetrucks (whose color thus again matched the color of the aesthetic, nonsymbolic dots) or yellow school buses (whose color thus resembled neither the symbolic green nor the nonsymbolic red dots). For firetrucks, map choices were consistently wrong at 5 to 6 years, mixed at 7 to 8, and consistently right at 9 to 10. For buses, performance was better overall, but only the oldest children were universally correct and justified choices by map creators intent. Thus, although 3-year-olds display representational insight, it is not until 9 or 10 that children fully understand that intentionally assigned meaning overrides attribute resemblance, allowing them to routinely interpret noniconic map symbols correctly.

The Spatial Nature of Maps

In addition to being symbolic, maps are *spatial* representations: Maps’ two-dimensional marks are distributed over a representational surface to depict spatial properties of the referent space. Importantly, just as cartographers select what is mapped and how content is symbolized, cartographers make choices that define geometric correspondences between referent space and representational space. Each map depicts the referent space from a particular viewing distance (affecting map scale), viewing angle (e.g., straight down vs. oblique), and viewing azimuth or direction (e.g., facing north vs. west). When a three-dimensional referent is mapped onto a two-dimensional surface (as in any map of large portions of Earth), the choice of projection (e.g., Mercator vs. Peters) affects which properties of the real space (distance, shape, size, angle) are preserved, because at least one property must be distorted when losing a spatial dimension. Thus the spatial meaning of any graphic mark or region of a map is no more automatically transparent than the symbolic meaning of any red line. Interpreting spatial meaning requires users' spatial cognition just as interpreting the symbolic meaning requires users' representational insights and concepts.

Two developmental approaches to spatial cognition have been particularly useful in our work. One is the triad of spatial concepts—topological, projective, and Euclidean—identified by Piaget and Inhelder (1948/1956) in their study of progressive spatial thinking (see Fig. 1). Topological concepts were said to be basic and available as early as the preschool years. Projective and Euclidean concepts were said to emerge together, gradually, during middle and late childhood. Subsequent work has shown that even infants can be sensitive to projective qualities (Quinn & Liben, 2008) and metric qualities (Newcombe, Huttenlocher, & Learmonth, 1999) while some adults have difficulty with both (Liben, 2006). Although these three spatial concepts thus do not emerge in a universal, lock-step sequence, they have been useful in predicting which mapping tasks will generally be solved earlier versus later in development and in organizing the search for individual differences in mapping performance.

Consistent with the hypothesis that topological concepts are developmentally more basic than projective or Euclidean concepts, when elementary-school children are asked to place stickers on maps to show flags' locations on a model (Liben & Downs, 1989) or in a field site (Kastens & Liben, 2007), accuracy is higher on test locations that allow the use of topological reasoning than on those that require the use of projective or Euclidean reasoning. Illustrative data are provided in Figure 2.

Also compatible with the position that metric concepts are challenging for young children are data showing preschoolers' difficulties in interpreting scaled representations (Liben & Downs, 1989). Illustrative is a preschooler who denied that lines on a road map could show roads because they were “not fat enough for two cars to go on” and denied that a rectangular shape on an aerial photograph could be his father's office building because “It's *huge!* It's as big as this whole map!” Children in the early primary grades also have difficulty identifying analogous locations across representations at different scales, errors that are significantly reduced in later life (Uttal, 1996).

At ages at which projective concepts are typically not well developed, children also have difficulty with maps depicting environments from unfamiliar viewing angles. For example, preschoolers have significantly greater difficulty identifying locations on a plan-view map (depicting the space from directly overhead) than on an oblique-view map, an angle closer to children's perceptual experience (Liben & Yekel, 1996). Also consistent with the importance of developing projective spatial concepts is the finding that children in early (but not late) elementary grades typically have great difficulty in finding locations and directions on a map of their classroom when the map is misaligned with the room (Liben & Downs, 1993).

In addition to revealing average differences in map performance across age, research also reveals dramatic individual differences within age. For example, children who had particular difficulty on a Piagetian projective task (similar to that shown in Fig. 1b) also had greater difficulty using unaligned maps (Liben & Downs, 1993); adults who failed the classic Piagetian Euclidean water-level task, in which respondents are asked to draw a line inside a tipped bottle to show the location of water, (see Fig. 1c) also had difficulty drawing a line on a map to show the orientation of a rod lying on the ground (Liben, Christensen, & Kastens, 2008).

In summary, the approach reviewed above begins by asking what concepts of space (topological, projective, or Euclidean) are tapped by various maps and mapping tasks and then examines empirical data to see whether mapping performance differs among people who have differing command of these basic spatial concepts.

The second approach informing our map research comes from Linn and Petersen's (1985) study of the developmental emergence of gender differences in spatial performance. By examining individuals' performance on a range of spatial tasks, they identified three categories of spatial skills—spatial perception, spatial visualization, and mental rotation—illustrated in Figure 3. In our work we have studied whether these three spatial skills are linked to performance on mapping tasks. Of particular interest is whether different categories of skills are differentially associated with performance on different mapping tasks.

In one study (Liben et al., 2008), college students took mental rotation, spatial visualization, and spatial perception tests and completed two mapping tasks. One mapping task was given outdoors: Participants were escorted to unfamiliar locations on campus and asked to mark each current location on a campus map. The other task was given at a computer where participants watched videotaped eye-level scenes of a walk through a park, controlling their route via their own mouse clicks. Their goal was to discover their location in the park and mark it on a plan map of the park, also displayed on the computer screen. Data showed that scores on the spatial tests, as a group, predicted scores on both campus and computer mapping tasks. However, *which* test predicted performance varied by task. Spatial visualization scores predicted campus (but not computer) performance, suggesting that flexible multistep strategies are particularly relevant for relatively open-ended mapping challenges. Mental rotation predicted computer (but not campus) performance, suggesting that mental rotation skills are particularly relevant when the map cannot be physically turned.

Explaining and Influencing Individual and Group Differences

As already explained, the primary goal of our work has been to understand the ways that mapping entails basic spatial concepts and skills. Our secondary goals include learning why individual and group differences in spatial and mapping skills occur and whether spatial and mapping skills can be fostered, reciprocally, through educational interventions. One motivation for finding ways to foster these skills is the observation that better spatial skills and more advanced spatial concepts are associated with greater success in a range of science, technology, engineering, and mathematics (STEM) curricula and careers. Enhancing spatial thinking might prove useful not only for advancing STEM outcomes in general but also for reducing the STEM gender disparity that may reflect, in part, the continuing male advantage in spatial skills (Liben, 2006; National Research Council, 2006).

Our research has examined the role of spatial and mapping experience in informal home and museum settings as well as the role of instructional guidance and curricula in classroom settings. Illustratively, we have found that parents' spontaneous discussions of spatial issues during picture-book reading predicted their preschool children's success on a spatial task (Szechter & Liben, 2004); that asking fourth-graders to reflect on the reasoning they used when deciding where to place their stickers on a map (i.e., encouraging their meta-cognition) improved the accuracy of their sticker placements (Kastens & Liben, 2007); and that a curriculum emphasizing map-to-world links led to improvements on both representational and field mapping tasks (Liben et al., 2002). Even within given developmental and ability levels, experience and instruction matter.

WHERE DO WE GO FROM HERE?

I end with the classic conclusion that "more research is needed." Here this conclusion reflects not only the truism that research invariably generates new questions but also the fact that mapping is undergoing radical change. For example, remote sensing technology now captures terabytes of geo-referenced information (e.g., meteorological data) that are too massive and too complex for the human mind to process without representational mediation. Disembodied voices from in-car navigation devices obviate drivers' needs to locate themselves within the larger environment, know their cardinal heading, plan a route, or decide which way to turn. Virtual realities enable people to explore distant towns without consulting maps to get there. Computer assisted design software, Google Earth™, and other visualization tools allow users to see buildings, objects, and landscapes from multiple distances and vantage points without physical movement or mental rotation.

Will such technologies make map skills atrophy, or might these technologies be harnessed to teach and enhance spatial and mapping skills (Liben, 2006; National Research Council, 2006)? Will early exposure to these technologies change the fundamental challenges of cognitive development? For example, we have long asked how children come to relate place representations to prior, embodied, real-world experiences. As children have earlier, more varied, and more numerous experiences with representational environments (e.g., Second Life® avatars, Skype™ visits with grandparents), will we need to ask instead how children come to connect real-world referents to their already well-established representational worlds?

In short, maps provide insights into the world that people inhabit. At the same time, research on the development of map understanding provides insights into the people who inhabit that world.

Recommended Reading

Liben, L.S. (2006). (See References). Overviews key constructs associated with spatial cognition in general and with mapping in particular; describes ways that map education may provide a useful inroad into spatial education; and discusses relevant developmental, gender, and individual differences.

National Research Council (2006). (See References). A report produced by an interdisciplinary team of scholars arguing for the importance of spatial thinking and education for a wide range of sciences, providing many illustrations of how spatial skills (including map-based skills) play an important role in science and science education.

Uttal, D. (2000). Seeing the big picture: Map use and the development of spatial cognition. *Developmental Science*, *3*, 247–286. Discusses the reciprocal relation between maps and spatial cognition and, joined with the associated commentaries and response, highlights critical conceptual issues in the topic of developmental map understanding.

Wiegand, P. (2006). *Learning and teaching with maps.* New York: Routledge. A compact book offering a pedagogical perspective on the development of map understanding, integrating scholarship on the development of map skills with cartography and education.

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Figure Captions

Fig. 1. The triad of spatial concepts identified by Piaget and Inhelder (1948/1956). Topological space encodes spatial qualities and relationships that are retained despite elastic distortion. Children with topological concepts can, for example, appreciate "next to," "in," and "on" relationships but not distance and angle. Thus, asked to copy models shown in row 1 of (a), young children can produce drawings preserving these spatial relations (see row 2), but asked to copy a triangle, circle, and square, they produce equivalent, undifferentiated closed shapes (figure adapted from Piaget & Inhelder, 1948/1956). Projective space relates objects to one

another in terms of straight "projected" lines, thereby allowing the coordination among perspectives. Children who understand projective space can determine how appearance changes with vantage point—for example, predicting how an array of mountains (b; from Piaget & Inhelder, 1948/1956) looks to someone seated at a different location from the child. Euclidean space involves the use of an abstract, container-like system such as Cartesian coordinate axes. Children who have constructed Euclidean concepts can, for example, conserve distance across locations, measure angles, and apply their horizontal and vertical coordinate framework to recognize that water in a tilted bottle (c) remains horizontal.

Fig. 2. Performance on a mapping task in relation to spatial demands of individual test items. Fourth-grade children were asked to place eight colored stickers on a campus map (upper left) to show the locations of eight colored flags that had been placed around campus. The remaining maps provide composites of children's responses for three flags (*N* = 141). Data are the “baseline” data of Kastens & Liben (2007) plus unpublished data from Kastens (personal communication). For the black flag, almost all stickers were placed in the correct or a nearby location. This high level of performance is attributed to the fact that the flag's location can be defined as on the statue, a definition requiring only topological concepts (see Fig. 1a). For the orange flag, children commonly identified the correct building, but many erred by placing their sticker on an incorrect corner; some placed their stickers on an incorrect building entirely. Identifying the correct building and corner draws on understanding the direction from which a given building is seen, thus involving projective concepts (see Fig. 1b). For the red flag, most children placed their sticker on the correct road, but many failed to identify the correct location along the road. Correct placement for this item draws on Euclidean concepts that allow the

identification of coordinate locations, measurement, and proportionality (see Fig. 1c).

Fig. 3. Illustrative measures of the triad of spatial skills identified by Linn and Petersen (1985). *Spatial perception* refers to the ability to recognize one's own position in relation to conflicting or embedding visual cues; an illustrative measure for this category (a) is the Witkin rod and frame task (see Linn & Petersen, 1985), in which respondents are asked to adjust a rod embedded in a tilted frame so that the rod is vertical. The respondent needs to rely on body cues because the stimulus is presented in a way that allows only the frame and rod to be seen. *Spatial visualization* refers to skill in solving problems that involve multiple steps and that can draw on a combination of verbal and visual strategies. An illustrative measure (b) is the Educational Testing Service paper-folding task (see Linn & Petersen, 1985), in which a paper is shown folded, a hole is then punched, and respondents select how the paper would look once unfolded. *Mental rotation* refers to skill in imagining the way that figures or objects look as they turn through space or are viewed from different directions. An illustrative two-dimensional task (c) based on Thurstone's Primary Mental Abilities test (see Liben, Myers, & Kastens, 2008) presents respondents with a model line figure and then asks respondents to mark any choices that show the model figure rotated in the plane (but not flipped over).