Is Cognitive Modularity Necessary in an Evolutionary Account of Development?

Nora S. Newcombe, Kristin R. Ratliff,
Wendy L. Shallcross and Alexandra Twyman

Chapter to appear in L. Tommasi, L. Nadel & M.A. Peterson (Eds.),
Assembling Brains: Cognition, Development and Evolution,
Vienna Series in Theoretical Biology. Cambridge, MA: The MIT Press.

Our species has many distinctive characteristics, including upright posture, opposable thumbs, large brains, language, tool use, and many others. Arguably, one of the key characteristics of *Homo sapiens* is a developmental one: the extended proportion of our life span that comes before sexual maturity (Gould, 1977). One of the crucial adaptive functions of this lengthy childhood is to allow for cognitive development. When a young organism must fend for itself, its interactions with the environment must be "good to go", and hence relatively preformed and inflexible. By contrast, human young can take their time, while protected by adults, to adapt to the environment in which they find themselves and to learn from the innovations and insights of prior generations. The same is true, albeit perhaps to a lesser extent, for other species in which there is a juvenile period before sexual maturity spent with mother, parents, or a band of adults.

Viewed in this way, one might assume that an evolutionary approach to cognitive development would stress plasticity and learning, and might seek to relate inter-species differences to differences in the length of the juvenile age period. However, in reality, characterizing the nature of cognitive development has involved a repetitive struggle between nativism and empiricism, in which nativism has lately had a fairly dominant hand. For a while, Piaget's constructivism seemed to provide a way out of this opposition. But as Piaget's influence waned in the late 1970s and early 1980s (Gelman & Baillargeon, 1983), a new nativism became the predominant mode of theorizing (e.g., Spelke, Breinlinger, Macomber & Jacobson, 1992). Alternative approaches appearing in the 1990s (Elman et al., 1996; Karmiloff-Smith, 1992; Siegler, 1998; Thelen & Smith, 1994) may collectively be called emergentist theories, although there are differences as well as similarities among them (see chapters in Spencer, Thomas & McClelland, in press). However, nativism (under the banner of “core knowledge”) has continued to be an attractive option for many cognitive developmentalists into the 21st century (Dehaene, Izard, Pica & Spelke, 2006; Spelke, 2000; Spelke & Kinzler, 2007).

The persistence of nativism is a curious situation; all concerned, including individuals seen by others as unvarnished proponents of one side or the other, have professed support for *interactionism*, the idea that genetics and environment interact in complex and bidirectional ways to create development (e.g., Marcus, 2004). However, nativism benefits from several advantages in the ongoing nature-nurture controversy. Chief among these advantages is the fact that it provides a simple and elegant story about how development and evolution fit together. In this way of thinking, adaptive pressures operate on a modular cognitive architecture (Cosmides & Tooby, 1992). This brand of evolutionary psychology has in fact argued that evolution could *only* work if our cognitive organization is modular, because otherwise there would be no distinct target for adaptive pressures. For example, the adaptive value of fluently recognizing others leads to selection for modular face recognition abilities, the fact that living in social groups demands attention to equity in exchange leads to selection for a cheater detection module (Cosmides & Tooby, 1989, 1992), and so on. Although modularity does not, strictly speaking, entail nativism (Barrett & Kurzban, 2006; Fodor, 2000; Karmiloff-Smith, 1992), the two concepts are deeply intertwined in theorizing of this sort. In addition, innate origins are identified with modularity because they were in fact explicitly advanced as an attribute of a cognitive module in Fodor’s original (1983) formulation of modularity.

The innate-module approach to the evolution and development of cognition is dramatically exemplified in recent proposals of an encapsulated geometric module that guides reorientation (Hermer & Spelke, 1994, 1996). We are normally oriented to our spatial environment as we move through it, maintaining awareness of our position using both internal tracking mechanisms and relations to external landmarks. However, if we pass through a dark cave, or tumble down a hill, we may look around with very little idea of where we are, and need to reorient. Clearly, reorientation is an adaptive problem—the person who does not solve it will be unable to get home, avoid dangers, or find food. Experiments originally done with rats (Cheng, 1986) and later done with human toddlers (Hermer & Spelke, 1994, 1996) showed that reorientation was accomplished using information about the geometric shape of an enclosure. For example, in a rectangular space, after disorientation, searches for food or other objects concentrate on two geometrically congruent corners, e.g., long wall to left of short wall. This pattern shows that geometric information is used to constrain likely search locations. Dramatically, when a prominent feature such as a colored wall or a corner panel potentially allows picking the correct spot, search remains evenly divided between the two geometrically congruent corners. The features are easy to notice and are used to guide search when there has been no disorientation. Hence, it seems that using geometric information to reorient is not only modular in the sense of making use of distinctive information uniquely relevant to the problem at hand (functional specialization) or in the sense of utilizing a specialized brain area (although there is some evidence there may be such an area; Epstein & Kanwisher, 1998). Rather, it seems that this was a module in a very strong sense: encapsulated and unable to accept functionally relevant information.

Human adults, however, do use non-geometric information to reorient (Hermer & Spelke, 1994, 1996). The transition from non-use to use of non-geometric information, between the ages of 5 and 6 years (Hermer-Vazquez, Moffet & Munkholm, 2001), poses an interesting issue for a nativist approach to cognition: how to account for developmental change. This challenge was answered by the suggestion that human language provides the tool for alteration of what would otherwise be a fundamental constraint on thought. When children acquire productive control of the terms “left” and “right”, they become able to conjoin geometric and non-geometric information in a fashion unavailable in the absence of a symbolic system (Hermer-Vazquez et al., 2001). Interestingly, this research has been cited enthusiastically by proponents of culturally- and linguistically-based approaches to cognitive development (e.g., Haun, Rapold, Call, Janzen & Levinson, 2006; Levinson, 2003).

The module-plus-language approach is, however, not the only way to conceptualize the evolution and development of a capacity for spatial reorientation. There are several difficulties with the hypothesis, including the facts that many non-human animals actually can use non-geometric information to reorient (see review by Cheng & Newcombe, 2005), that human toddlers can use non-geometric information to reorient in larger and more ecologically valid spaces than those used in the original research (Learmonth et al., 2001, 2002), and that language does not appear to have a unique role in adult use of non-geometric information to reorient (Ratliff & Newcombe, in press). The main purpose in this chapter is to explore the promise of a different view of the relation of evolution and development, one more in the tradition of the plasticity-due-to-neoteny way of thinking. We argue both for a different view of orientation and reorientation and, more generally, for a different view of the relation between evolution and development than the currently popular one.

In the first section of the chapter, we outline an *adaptive combination* approach to spatial cognition and spatial development, and in the second section, we review recent findings that support it. (See Newcombe & Huttenlocher, 2000, 2006, for more extended reviews of spatial development and this approach to it.) In the third section, we critique two recent arguments for innate geometry: a demonstration that features alone cannot be used to reorient (Lee, Shusterman, & Spelke, 2006), and data on geometric concepts in the Munduruku (Dehaene, Izard, Pica & Spelke, 2006). In the concluding section, we place the adaptive combination view in the framework of a prepared learning approach to cognitive development and of an evolutionary approach to psychology that does not require cognitive modularity.

Adaptive Combination Approach to the Development of Reorientation

People are frequently confronted with questions that require spatial estimation, such as “Which way should I head to get home from the library?” or “Where did I leave my cell phone?”

In answering such questions, there is considerable evidence for the use of multiple sources of information. Cheng, Shettleworth, Huttenlocher and Rieser (in press) review this evidence and theorizing, which includes several Bayesian models that show that such combination frequently maximizes the average accuracy of responses. Cheng et al. structure their review around three kinds of situations in which combination occurs, including when two or more currently-available metric estimates are combined (e.g., visual and haptic information; Ernst & Banks, 2002), when current information is combined with the average of past experience (Kersten & Yuille, 2003), and when current information is combined with categorical information that may or may not derive from past experience (Huttenlocher, Hedges & Duncan, 1991; Huttenlocher, Hedges & Vevea, 2000).

The overall thrust of the Cheng et al. (in press) review is that spatial conclusions are typically supported by various information sources whose use derives at least in part from experience. For example, recalibration of the relation of optic flow to distance traveled occurs when the relation is changed because one is walking on a treadmill that is itself moving (pulled by a tractor; Rieser et al., 1995). Learning may work in one of two ways. First, it sometimes determines the relative weighting of the various information sources, with weightings affected by several factors, including the reliability of the source, how variably or inexactly it is coded, how perceptually salient it is, and how frequently it has been used in the past, e.g., H.B. Wang, Johnson, Sun & Zhang, 2005. Second, when two information sources lead to incompatible responses, learning may determine which of the sources will be preferentially relied on, i.e., shaping a hierarchy of responses to be tried sequentially rather than production of an integrated estimate. In sum, the adaptive combination approach involves the propositions that there are multiple sources of spatial information and that those sources are either integrated using weighting mechanisms or hierarchically arranged in order of preference, and that those weightings and orderings are, at least in part, learned in the course of interaction with the spatial environment.

What happens when two information sources provide redundant information? In some cases, both are learned, but in other cases, one of the two is ignored, or learned less easily or thoroughly than it would have been when presented alone. Classically, this phenomenon has been described either as *blocking* (when one information source has already been learned and prevents learning of a second source) or as *overshadowing* (when the two sources are presented concurrently, and the learning of either or both may be affected). Blocking and overshadowing seem to contradict the idea of adaptive combination, in that an information source is ignored even though it might contribute to increased precision of spatial estimation, or even provide a way of estimating location when it would be otherwise impossible (as when the first source becomes perceptually unavailable, or unreliable). In addition, in terms of the geometric module hypothesis specifically, there are findings that show that learning distinctive features that mark a goal does not block learning of the geometry of an enclosure (Hayward et al., 2003; Pearce et al., 2001; Wall, Botly, Black & Shettleworth, 2004). One conclusion that could be drawn from such a lack of blocking effects is that the featural and geometric information are processed separately, perhaps in a fashion that might be called modular.

However, Miller and Shettleworth (in press) provide a non-modular account of these findings on overshadowing and blocking, as well as one consistent with the adaptive combination approach. In doing so, they also bring order to the literature by explaining other findings that seem contradictory to overshadowing and blocking, in which learning one kind of information is easier or quicker or more robust when the other kind is present (e.g., Pearce, Graham, Good, Jones & McGregor, 2006) or in which blocking or overshadowing are sometimes observed (e.g., Gray, Bloomfield, Ferrey, Spetch & Sturdy, 2005). Nolan and Shettleworth present an operant model related to the Rescorla-Wagner associative learning model. In this account, features and geometry are both encoded on every trial, and the contingencies of one kind of information influence learning of the other kind, and vice versa.

In summary, although many issues remain to be worked out in detail, there is growing reason to believe that spatial behavior typically depends on combining information from a variety of sources. This kind of theorizing is very different from that sometimes espoused in the literature, as, for example, when R.F. Wang and Spelke (2002) postulated that spatial behavior is determined completely by the geometric module for coping with reorientation, coupled with memory for viewpoint-specific representations of local sections of the environment that are related to each other through egocentric spatial updating. However, a recent critique of the R.F. Wang and Spelke argument by Burgess (2006) shows that egocentric and allocentric spatial representation co-exist and interact in supporting spatial behavior, in general accord with the adaptive combination point of view.

Recent Findings Supporting An Adaptive Combination to Reorientation

In this section, we argue that the co-existence and interaction of various kinds of spatial information for reorientation, as postulated by the adaptive combination view, is necessary to explain the data on development of the ability to reorient. Specifically, use of geometric and non-geometric information to reorient fluctuates systematically as a function of variables that affect the certainty with which the two kinds of information are encoded, their salience, and their cue validity. Such fluctuation could not be predicted by a modular theory. First, we examine fluctuation as a function of size of the enclosed space. Second, we discuss recent work on rearing and training effects. Third, we look at the effects of full enclosure as compared with a geometric outline that is only suggested by separated environmental elements, an issue that has the potential to shed light on the modularity issue but whose status is not yet empirically clear.

Room Size Effects

In the literature on reorientation in human children, the first demonstration that very young children do sometimes use features as well as geometry to reorient came from experiments by Learmonth, Newcombe and Huttenlocher (2001). The contrast between the Learmonth et al. findings and those of the Spelke group were quickly shown to be due to the fact that the

Learmonth et al. experiments were done in a room with quadruple the area of the Spelke group's experiments (Learmonth, Nadel & Newcombe, 2002). The two papers by Learmonth et al. provide three challenges to the geometric module approach to the development of reorientation. First, children are using features as well as geometry by 18 months, at an age much younger than the age at which they control production of the terms "left" and "right" (and recall that acquisition of these linguistic terms is the only developmental mechanism postulated by the Spelke group). Second, a geometric module that only operated in extremely small spaces would not be very useful in our environment of adaptation; in fact, even the larger room used by Learmonth is quite small by the standards of the real world. Third, the modularity view cannot provide a cogent account of why the size of the space matters. The size of the experimental enclosure also appears to have a profound effect on non-human species, who have also shown a preference for using geometric information in small spaces, while relying on non-geometric featural cues during reorientation in larger spaces (Sovrano et al., 2005; Vallortigara et al., 2005).

So, what is the adaptive combination account of the room size effect? According to an adaptive combination view, geometric information would be expected to predominate in studies where room shape is easily encoded with great certainty and low variability, as is true in most work so far, which has used fully-enclosed spaces with a simple regular geometric shape such as a rectangle, triangle or rhombus (an issue discussed in a later section of this chapter). In contrast, the non-geometric features are often likely encoded variably and with lower salience, for example if they are small and mobile (Hermer & Spelke, 1996, Experiments 3, 4 and 6; Gouteux, Thinus-Blanc, & Vauclair, 2001). In terms of the room size effect, an important variable is likely to be whether the features are distal or proximal. The further away a feature is located from an organism the greater the strength of encoding. Imagine movement around a local area. This movement creates very large variability in the location of a proximal feature. In contrast, movement creates only small variability in the location of distal features, according to an adaptive combination model (Newcombe & Ratliff, 2007).

Learmonth, Newcombe, Sheridan and Jones (in press) explored how landmark proximity affects search patterns to produce the differences found between room sizes. They also examined the effect of whether or not it was easy to move around a space; smaller spaces constrict movement, which is known to lead to reduced spatial coding (for rats, Foster, Castro & McNaughton, 1989; for children, Acredolo, 1978, Acredolo & Evans, 1980, McComas & Dulberg, 1997). Children between 3 and 6 years performed the reorientation procedure of searching for a toy hidden in one of the four corners of a larger 8 by 12 foot rectangular room with one colored wall. Some of the children had their movements restricted by being placed within a small, centrally located 4 by 6 foot unfeatured rectangular area located within the larger room.

The results showed that at least three factors affect the age at which features are used to reorient. First, when the colored wall was more distal than it could be in the small room, children succeeded in using the feature to guide search at 4 years instead of 6 years, even when their movement was restricted. Second, the ability to move freely in the larger room also has an impact. When action is restricted, using features to reorient does not appear until 4 years, as compared to 18 months, the age at which use of features is first evident when active movement is allowed (Learmonth et al., 2001). Third, when the toy was hidden in a corner of the unfeatured central enclosure, thereby close to the child but far from the landmark, successful orientation did not occur until 6 years of age as compared to success at 4 years old when targets were placed adjacent to the distal colored wall landmark. These variable ages of transition in non-geometric feature use suggests the overall inadequacy of a modularity-plus-language view.

Size of the experimental enclosure also changes reorientation strategies when a non-geometric feature, such as a colored wall, is displaced during testing from the location learned during training. When the learned geometry and feature locations are placed in conflict, fish (Sovrano, Bisazza, & Vallortigara, 2007) as well as chicks (Chiandetti, Regolin, Sovrano & Vallortigara, 2006; Sovrano & Vallortigara, 2006) reorient by the geometry of a small enclosure, but the animals switch their search strategy in the larger spaces, relying on the current location of the non-geometric feature to reorient. Applying this conflict paradigm to identify the hierarchy of spatial cues used during adult reorientation, Ratliff and Newcombe (2007) found that the adults used geometric information to a greater degree in a small (4x6ft.) room whereas adults reoriented by the location of a feature in a larger (8x12ft.) room. Additionally, when training and testing occurred in geometrically equivalent rooms but of different sizes (ratio of long to short walls remains constant although the room areas are different), reorientation behavior was consistently dominated by the feature location rather than the geometric shape of the room in both a large and small test room. Such search patterns suggest an adaptive approach to reorientation through integrating geometric and non-geometric information depending on the certainty of encoding, reliability, and salience of the two types of spatial cues.

Effects of Training and Rearing

A core element of the adaptive combination approach is the idea that spatial coding will be dynamically affected by experience, both recent experience (training effects) and early experience in a juvenile period (rearing effects). By contrast, the modularity-plus-language position has little room for such ideas, proposing instead that a fixed innately-determined module can be changed only by the human capacity for linguistic encoding that can over-ride the outputs of the module. There is considerable evidence for training effects, however, and some accumulating evidence for rearing effects. In this section, we look at the two sub-issues in turn.

Training

Many training experiments have shown that flexibility of cue use can be achieved with mature participants, given the appropriate experience. Initially, pigeons were shown to flexibly use feature and geometric information, depending on the initial training experience (Kelly, Spetch, & Heth, 1998). All pigeons were trained to find a hidden food source in an enclosed rectangular environment. One group of pigeons was trained with only geometric information while the other group was also trained with distinct feature information at each corner. The pigeons that had been initially trained with only geometric information were then retrained with the same feature information as the first group. During the test phase, the features were rotated 90° so that the correct feature corner was now in an incorrect geometric location. The pigeons that had been initially trained with features mainly selected the featurally correct corner. In contrast, the pigeons with the initial geometry training divided the choices between the two geometrically correct corners and the correct feature corners.

To extend this work, Kelly and Spetch (2004a; 2004b) trained pigeons and adults with a two-dimensional schematic form of the reorientation task. On a computer screen, a rectangle appeared with four landmarks at each corner. The pigeons and adults were divided in two groups, half of which were trained first only with geometric information, followed by geometric and feature information. The other half was trained with the reverse order. In the conflict trials, all of the adults choose the featurally correct corner and therefore there was no effect of the order of training. Thus, for schematic diagrams, feature information may be more salient than geometric information for human adults. For pigeons, in contrast to Kelly, Spetch, and Heth (1998), the training order did not influence the choice on the conflict trials. All of the pigeons divided the search equally between the geometrically correct corners and the correct feature corner. However, there was a difference in the training procedure. The pigeons in Kelly et al.'s (1998) experiment only received the feature and geometry training before the conflict trial. The pigeons in Kelly and Spetch's (2004b) experiment received the feature and geometry training, followed by a geometry-only training session before the conflict test. One dose of geometry training, either before or after feature training, was enough to boost the use of geometric information for pigeons. Thus, it appears that the relative weightings of feature and geometry cues for pigeons can be quite malleable.

It also appears that the relative weighting of geometric and non-geometric information for children can be influenced by experience. As mentioned earlier in the chapter, children below the age of six are not normally able to reorient in a small 4 x 6 foot room using non-geometric cues

(Hermer & Spelke, 1994, 1996). However when given practice using non-geometric information, four and five year old children can succeed at the task in the same size of enclosure (Twyman, Friedman & Spetch, submitted). These children were asked to practice the reorientation task in an equilateral triangle, which has no distinctive geometric information. Each of the walls was a different color, so the children were given practice using non-geometric cues to reorient. Children were then tested in the small rectangular shaped room and were able to reorient using both geometric and non-geometric cues. When children were given practice in the standard small rectangle room with the feature wall, a more subtle feature training task, these children were also able to conjoin geometric and non-geometric cues after a relatively small number of trials. Thus, it appears that practice with non-geometric cues – both salient and subtle – can influence the use of geometric and non-geometric information.

Rearing

Rearing experiments take the principles of training experiments one step further and dramatically display the flexibility of cue use. One of the first studies to demonstrate this flexibility was with wild-caught mountain chickadees (Gray et al., 2005). These birds live in forested areas lacking salient geometric cues, in contrast to the standard lab rearing environment. The chickadees were trained to find food in the corner of an enclosed rectangle with one salient blue feature wall. When the target corner was adjacent to the feature wall, the chickadees did not encode the geometry of the enclosure. However, when the target corner was away from the feature wall, then the chickadees did encode the geometry. Thus, the use of geometric and non-geometric information depended on the proximity of the nongeometric, or featural information to the target corner.

To further understand the effects of rearing, two groups of researchers used a laboratory version of the wild caught chickadee experiment. Brown, Spetch and Hurd (in press) reared fish, convict cichlids, in either a circular (lacking geometry) or rectangular tank (salient right angles). Unlike the chickadees, all of the fish encoded the geometry of the rectangle. However, there were still differences between the groups. Fish that had been reared in the circular tank more rapidly learned to use features than fish that had been reared in the geometry rich rectangular tank. Further differences were revealed on conflict trials, where the feature wall is moved from a short wall to a long wall or vice versa, placing the learned geometry in conflict with the feature location. While this task may seem unfair for the subject, it reveals the hierarchy structure of the cues. Fish that had been reared in the circular tank chose the featurally correct corner more often than their rectangular reared counterparts who more often chose based on geometry. Thus, the use of geometric and non-geometric information was influenced by rearing environment of the convict cichlids.

Chiandetti and Vallortigara (submitted) examined the influence of rearing environment on the performance of chicks on the reorientation task. This particular species is quite precocial. After hatching, chicks were placed in either a rectangular or circular cage for 2 days before training began on the third day of life. When training occurred both in the presence or absence of features, all chicks encoded the geometry of the environment. Thus, for chicks, it appears that the rearing environment did not influence the hierarchy of spatial cues. However, there are two ways of looking at the data. On one hand, this species may already be near adult levels of maturation at hatching, thus the use of geometric and non-geometric cues has already been crystallized. On the other hand, it is possible that if either the chicks had been reared for a longer period in the environments or if conflict trials had been conducted, differences in the hierarchy may have been observed.

At this point, we are just starting to understand some of the differences in the flexibility of use of geometric and non-geometric cues. It is possible that there may be species specific reasons why malleability is found in some cases, such as the children or the mountain chickadees, compared to the more crystallized pattern in other cases, such as the chicks or fish. It is also possible to look at these data as they relate to the developmental period. If one looks at the spectrum from precocial to altricial, it is possible that the amount of flexibility within the adaptive combination model may depend on where an organism lies on this spectrum. At the precocial end, we may find the chicks are “good to go” as soon as they hatch and thus their spatial navigation system may be crystallized early on. At the other end of the spectrum, we might find that altricial species, such as humans, elephants, and hippopotamuses, with an elongated period of development, may be able to support a more flexible cognitive system, including spatial navigation as one example. Future research on species differences could prove to be worthwhile.

Inferred Geometric Information

Natural environments do not typically contain fully enclosed regular geometric spaces. The appeal of the geometric module hypothesis rests in part on the proposition that geometric aspects of the environment such as cliff faces and river courses are unlikely to change, while the coloration or texture of cliffs or rivers may change with the season or the weather (Gallistel, 1990). However, cliff faces or river courses are extended in space but they rarely delineate more than a portion of the area surrounding a person or animal, and what they do delineate, they do so in a complex and irregular way. In addition, many natural environments, such as open savannah areas, are fairly uniform except for discrete landmarks (Poucet, 1993). These observations have several implications for the geometric module hypothesis. First, they suggest that the typical experiment conducted so far tests the role of geometry in reorientation at “industrial strength”, namely when there is minimal uncertainty regarding the shape and when the geometry can be easily encoded from the ratio of long and short sides meeting at a right angle. Second, following from the first point, they suggest that a crucial test of the geometric module hypothesis in an evolutionary-adaptive context is whether geometry can be used in cases where it must be inferred from fragmentary information, and whether, if so, its strength is reduced when this is the case.

It appears that human adults can use geometry that is only suggested by the presence of separated landmarks marking the vertices of a geometric figure (Gouteux & Spelke, 2001; Kelly & Bischof, 2005), as can rats (Gibson, Wilks & Kelly, in press, although note that Gibson et al. changed the position and orientation of the arrays rather than disorienting the rats). However, nutcrackers do not use geometry defined in this way (Kelly, 2005), which is a puzzling finding given that animals able to fly would appear to be particularly advantaged in discerning overall relations among separated aspects of the environment. The situation with regard to development of this ability in human children is not clear. Gouteux and Spelke (2001) found that children of 3 and 4 years need at least a set of partial extended surfaces, although not necessarily a closed figure, to use geometric information. In addition, in a series of investigations involving the use of maps (and so not directly relevant to the disorientation paradigm, although arguably still suggestive), Vasilyeva and Bowers (2006) found that the ability to infer geometric information from partial information improves markedly between the ages of 3 and 6 years. Similarly, Gibson, Leichtman, Kung and Simpson (in press) found that children could not use the geometry of separated points on a computer screen to locate targets until 6 years of age. However, on the other hand, Garrad-Cole, Lew, Bremner, and Whitaker (2001) found that children as young as 18 to 24 months succeeded in using the geometry of four separated objects to define search (as well as using featural information when available). Further studies using looking paradigms rather than search techniques showed sensitivity to the distances separating discrete objects at ages as young as 12 to 18 months (Lew, Foster & Bremner, 2006) and even 6 to 12 months (Lew, Foster, Bremner, Slavin & Green, 2005).

If one sets aside the studies of mapping or search on computer monitors, as well as the studies using looking techniques, as not directly relevant to search following disorientation, there is a straightforward contradiction between the studies of Gouteux and Spelke (2001) and Garrad-Cole et al. (2001). Cheng and Newcombe (2005) suggested two points of contrast: the use of a reference memory task (Garrad-Cole et al.) versus a working memory task (Gouteux and Spelke), and the fact that parents conducted experimental procedures with children in Garrad-Cole et al.'s study. There may well be other differences, including the placement of the boxes with respect to a larger enclosing space (Lew et al., 2006). The whole question deserves a closer look, which should not only look at methodological variables that might account for the discrepancy but which would also compare the extent to which partial geometry is relied on relative to fully-specified geometry and relative to features. The latter question is key to the theoretical debate, because the adaptive combination position clearly predicts that use of geometry should be weakened when its encoding would be expected to be more uncertain.

Recently, Kelly and Bischof (2005) have begun to take a look at the relative use of partial versus fully-specified geometry. Human participants were presented with a non-immersive three dimensional reorientation computer task. A rectangular room was displayed on the screen with uniquely colored and shaped landmarks in each corner. This environment contains two types of geometric information: fully-specified surface information and partial information from a configuration of objects. The walls of the rectangle create a surface geometry. The relation between the landmarks also creates a rectangle and thus could be classified as configuration geometry. The weighting of surface and configuration geometry depended on the initial experience. Participants were trained either with surface geometry, configuration geometry, or both. At test, the surface and configuration geometry were placed in conflict. Those participants who were presented with only one useful type of geometry weighted that category of geometry more heavily than the other type. For participants trained with both types of geometry, the searches were divided equally between surface and configuration geometry. Thus, the hierarchy of surface and configuration geometry depends on experience for adults, in accord with the adaptive combination view, but it was not clear that there was a preference for fully-specified information over the configuration. However, this fact may be specific to use of human adults, of computerized testing, or of the training regime.

Two Recent Arguments for Innate Geometry

So far, most of this chapter has concentrated on the adaptive combination view of how organisms perform spatial reorientation tasks. Such a view is consistent with what we know about spatial functioning more generally—mobile animals seem to navigate using a wide variety of sources of relevant information. It is also consistent with plasticity approaches to evolution and development, as we will discuss in more depth in the next and last section. However, the innate modularity approach to the evolutionary and developmental issues has continued its popularity, despite critiques and empirical disconfirmations of many of its findings or predictions. In particular, two recent articles have advanced arguments for retaining this approach to spatial development. The first is directly relevant to the geometric module debate; the second is only indirectly relevant but is discussed here because of the considerable attention it received when it appeared.

Can Features Alone Be Used to Reorient?

Lee et al. (2006) questioned what role landmarks might serve in 4-year-olds' reorientation. Specifically, they questioned whether landmarks would serve as reorientation cues or as beacons for an object's location. In order to probe this question, they placed three containers in an equilateral triangle configuration in the center of a circular room. For the majority of their experiments, they used two blue boxes (the indistinct containers) and one red cylinder (the distinct container) in which they hid a sticker across a series of trials. Their logic was that if children directly associated landmarks to locations, then they should only succeed when the object was hidden at the distinctive container. Children correctly found the target sticker when it was hidden at the cylinder whereas their searches were at chance when either of the two identical boxes covered the sticker (or stickers). From these search patterns, they concluded that children used the red cylinder only as a direct cue to an object's location. From their findings, they propose that:

> "behavior following reorientation depends on two distinct processes: a modular reorientation process that is sensitive only to geometry and an associative process that directly links landmarks to goal locations (p.581)."

In responding to these bold assertions, Newcombe, Jones, and Shallcross (2007) pointed out that the small, moveable landmarks placed on top of the targets used in Lee et al. may not be used because they lack the trustworthiness of large, stable landmarks and that, in addition, the area they defined was quite small. They suggested an alternative way to examine the use of features to reorient when associative processes can be ruled out, using an octagon with alternating short and long sides. If the octagon contains one colored wall, one examines the children's ability to discriminate among hide boxes located at three all white corners that are geometrically congruent.

The first step is to examine reorientation in an octagonal space with all white walls, because no prior research has used such a complex geometry. Newcombe, Jones, Shallcross, and Ratliff (2006) found that 2- and 3-year-old children used the geometry of the space to guide their searches. Children were reliable in choosing boxes that bore a geometrically-equivalent relationship (e.g., long wall on the left connected to a short wall on the right) to the box where the target object (a toy duck) was hidden. These results provided the foundation for the critical test; reorienting in the octagon with one long red colored wall feature.

In the octagon with the red wall, Newcombe, Jones, and Shallcross (2007) found that 3- and 5-year old children were able to reliably choose the correct corner in the cases in which children searched for the target in the all-white corners (hide box did not border the red wall). Their correct searches were significantly greater than the average of the 2 other geometrically-correct corners that bordered white walls. These results demonstrate that children in fact use features to reorient in a relatively large complex environment in a non-associative fashion.

Geometric Principles among the Munduruku.

The Munduruku are an Amazonian group who live in isolated villages and have little access to schools. Their language is reported to have few words for geometric or spatial concepts, they do not possess instruments for spatial measurement, and they do not use or draw maps to any great extent. Thus, if cultural or linguistic transmission were essential to the formation of basic geometric concepts, the Munduruku would be expected to perform poorly when asked about such fundamental concepts as parallelism or congruence. On the other hand, if the human mind comes equipped with the prerequisites for spatial thought, they would be expected to be able to recognize such concepts. Dehaene et al. (2006) evaluated geometric thinking among Munduruku children and adults by showing participants panels of six figures (using a solar-powered laptop). Five figures shared a key geometric characteristic that the other one lacked. For instance, there might be five pairs of parallel lines and one pair of lines that did not run in parallel. Crucially, the five sets of parallel lines varied among themselves in several ways, such as their orientation and the distance between the paired lines. When asked to point out the “weird” or “ugly” stimulus, the Munduruku reliably chose the geometrically odd figure, such as the non-parallel lines, as predicted by the “core knowledge” position.

The results seem to show strong support for a hard-wired view of human cognitive ability, as was heavily stressed in media coverage of the study by outlets such as the *New York Times* (Bakalar, 2006). However, some aspects of the data support plasticity (Newcombe & Uttal, 2006). First, Dehaene and his colleagues tested American children and adults as a comparison group for their Amazonian sample, and they repeatedly found that American adults did better than Munduruku of any age, as well as better than American children. This improved performance shows us that something about culture, language or education likely helps us build a more robust edifice on the foundation of our core intuitions. Second, the Munduruku performed particularly poorly on items involving geometric transformations, and the fact that American adults can cope with such items is noteworthy because it is likely of practical importance to performance in science and technical disciplines. Third, Dehaene et al. also note, though they did not test, that it is possible that the geometric intuitions they assessed are acquired progressively during the first 6 years of life, i.e., at ages younger than those they studied. Finer-grained study of geometric intuitions and mapping ability in Munduruku infants and very young children might show a progression of success, as has been found in previous studies of American infants and preschoolers, who often do *not* seem able to cope with some of the concepts for which the older American and Munduruku children showed success.

Plasticity and Modularity in Cognitive Development

Must we choose between plasticity and innate modularity, in an only slightly refreshed version of the nativist-empiricist debate? Perhaps not. Evolution and development have recently come together in the modern study of biology, in the form of evolutionary developmental biology, sometimes called Evo Devo. The main ideas of this line of research are said to be innovation, modularity, plasticity, emergence and inherency (Müller, 2005). This list of traits, and in particular the inclusion of modularity along with plasticity and emergence, points to the potential of this conceptual framework for allowing the formulation of integrated accounts of cognitive development that get beyond old dichotomies. Similarly, Barrett and Kurzban provide a road map to rapprochement in writing that, "Emergentism should not be viewed as an alternative to an evolutionary approach…….In particular, the error is the view that proximate and ultimate causation are competitors" (2006, p. 637). In other words, the ultimate causation created by adaptive pressures can be executed proximately in a variety of ways, and in particular, by endowing young organisms with prepared learning propensities rather than explicitly preformed representations (Greenough, Black & Wallace, 1987).

Consider the research area in which the notion of prepared learning was first proposed--the example of specific hungers. When investigators noted that rats deficient in some essential nutrient, such as thiamine, preferred to eat thiamine-rich diets to their usual fare, it was initially natural to postulate a "wisdom of the body" that recognized specifically what was lacking and sought it out. However, Rozin and Kalat (1971) showed that a general aversion to diets that create illness, such as those caused by vitamin deficiency (or poisonous substances) leads to a general preference for novel food items. There is no specific recognition of what is needed. Thus, an evolutionarily-important goal (avoiding illness) can be reached by the provision of a general rule (try new foods if you feel bad) rather than specific knowledge (look for thiamine).

A similar but more recent example of the role of learning in understanding the evolution of development comes from Dukas' work on perceptual learning (this volume). Whether or not it pays for an organism to specialize in recognizing camouflaged food items depends on the variety of foods in the environment: if food is plentiful, and much of it is easily identified, then an investment in the perceptual learning required to harvest such food is ill-advised. However, when camouflaged foods are the predominant sources of nutrition, perceptual learning is beneficial. In addition, when there are several camouflaged food sources, which prey a predator learns to recognize is a matter of chance, with the beneficial effect that specializations will vary across predators so that no one food source is as likely to be exhausted. In this case, an evolutionarily important goal (feeding) can be reached by the availability of a capacity for perceptual learning that occurs only in certain environments.

Is modularity required for a prepared learning approach to cognitive development? The answer depends on one's definition of modularity. The kind of modularity that Müller had in mind when he included it on his list of attributes of an Evo Devo approach is quite different from the kind of modularity stressed by Fodor (1983). As originally proposed by Fodor (1983), modularity was a strictly-defined concept requiring demonstration of several attributes, notably encapsulation from other informational sources and associated resistance to change, and was said to characterize sensory input more than central processes. However, the term "modularity" quickly came to refer simply to the idea that there may be neural and functional specialization for processes such as face or place recognition (e.g., Epstein, & Kanwisher, 1998, Kanwisher, et al., 1997) and that evolution worked by selection pressure on such specializations (Cosmides & Tooby, 1992). Unfortunately, subsequent authors have often been quite unclear about what they have in mind when they use the term. Newcombe and Ratliff (2007) argued that encapsulation is central to a clear definition of modularity and that when researchers simply mean neural specialization, they should say so, rather than using one term to mean many different things. Barrett and Kurzban (2006) disagree, saying that encapsulation as well as various other criteria are unimportant to modularity, and instead suggest that "module" is one way of talking about the simple fact of functional specialization (Barrett & Kurzban, 2006).

In summary, we have argued in this chapter against the idea that evolution can only work to create cognitive advances by affecting selection for innately-based and encapsulated modules. It might do so, but it need not. Instead, and more consistent with the existence of a lengthy juvenile period that itself may have overall evolutionary value, our species may have been subject to selection pressures for prepared learning that enables flexible accommodation to the vast array of environmental niches into which we have been able to live successfully. Such preparation would include starting points for learning as well as powerful learning algorithms, and that initial equipment may lead to emerging cognitive and neural specialization.

References

Acredolo, L. P. (1978). Development of spatial orientation in infancy. *Developmental Psychology, 14*, 224-234.

Acredolo, L. P. & Evans, D. (1980). Developmental change in the effects of landmarks on infant spatial behavior. *Developmental Psychology, 16,* 312-318.

Bakalar, N. (2006, January 24). Mastering the geometry of the jungle (or doin' what comes naturally). *The New York Times*, pp. F3.

Barrett, H.C. & Kurzban, R. (2006). Modularity in cognition: Framing the debate. *Psychological Review, 113,* 628-647.

Brown, A.A., Spetch, M.L., & Hurd, P.L. (in press). Growing in circles: Rearing environment alters spatial navigation in fish. *Psychological Science*.

Burgess, N. (2006). Spatial memory: How egocentric and allocentric combine. *Trends in Cognitive Sciences, 10,* 551-557.

Cheng, K. (1986). A purely geometric module in the rats spatial representation. *Cognition, 23,* 149-178.

Cheng, K. & Newcombe, N.S. (2005). Is there a geometric module for spatial orientation? Squaring theory and evidence. *Psychonomic Bulletin & Review, 12,* 1-23.

Cheng, K., Shettleworth, S.J., Huttenlocher, J., & Rieser, J.J. (in press). Bayesian integration of spatial information. *Psychological Bulletin*.

Chiandetti, C., Regolin, L., Sovrano, V.A. & Vallortigara, G. (2006). Spatial reorientation: The effects of space size on the encoding of landmark and geometry information. *Animal Cognition, 10,* 159-168.

Chiandetti, C. & Vallortigara, G. (submitted). An innate geometric module? Effects of experience with angular geometric cues on spatial reorientation based on the shape of the environment.

Cosmides, L. & Tooby, J. (1989). Evolutionary psychology and the generation of culture 1. Case-study- A computational theory of social-exchange, *Ethology and Sociobiology, 10,* 51-97.

Cosmides, L. & Tooby, J. (1992). Cognitive adaptations for social exchange. In J. Barkow, L. Cosmides, & J. Tooby (Eds.). *The adapted mind*. New York, NY: Oxford University Press.

Dehaene, S., Izard, V., Pica, P. & Spelke, E. (2006). Core knowledge of geometry in an Amazonian indigene group. *Science, 311,* 381-384.

Elman J., Bates, E., Johnson, M., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness: A connectionist perspective on development*. Cambridge, MA: MIT Press.

Epstein, R. & Kanwisher, N. (1998). A cortical representation of the local visual environment. *Nature, 392*, 598-601.

Ernst, M.O. & Banks, M.S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature, 415*, 429-433.

Fodor, J.A. (1983). *The modularity of mind.* Cambridge, MA: MIT Press.

Fodor, J.A. (2000). Replies to critics. *Mind & Language, 15*, 350-374.

Foster, T., Castro, C., and McNaughton, B. (1989). Spatial selectivity of rat hippocampal neurons: dependence on preparedness for movement. *Science, 244*, 1580-1582.

Gallistel, C.R. (1990). *The organization of learning.* Cambridge, MA: MIT Press.

Garrad-Cole, F., Lew, A.R., Bremner, J.G. & Whitaker, C.J. (2001). Use of cue configuration geometry for spatial orientation in human infants (*Homo sapiens*). *Journal of Comparative Psychology, 115*, 317-320.

Gelman, R., & Baillargeon, R. (1983). A review of some Piagetian concepts. In J.H. Flavell and E.M. Markman (Eds.), *Handbook of child psychology*, Vol. 3, (pp. 167–230). New York, NY: Wiley.

Gibson, B.M., Leichtman, M.D., Kung, D.A. & Simpson, M.J. (in press). Use of landmark features and geometry by children and adults during a two-dimensional search task. *Learning and Motivation*.

Gibson, B.M., Wilks, T.J. & Kelly, D.M. (in press). Rats encode the shape of an array of discrete objects. *Journal of Comparative Psychology*.

Gould, S. J. 1977. *Ontogeny and phylogeny*. Cambridge, MA: Harvard University Press.

Gouteux, S., Thinus-Blanc, C., & Vauclair, J. (2001). Rhesus monkeys use geometric and nongeometric information during a reorientation task. *Experimental Psychology: General, 130,* 505-519.

Gouteux, S. & Spelke, E.S. (2001). Children’s use of geometry and landmarks to reorient in an open space. *Cognition, 81*, 119-148.

Gray, E.R., Bloomfield, L.L., Ferrey, A. Spetch, M. L., & Sturdy, C.B. (2005). Spatial encoding in mountain chickadees: features overshadow geometry. *Biology Letters*, *1*, 314-317.

Greenough, W.T., Black, J.E. & Wallace, C.S. (1987). Experience and brain development. *Child Development, 58,* 539-559.

Haun, D.B.M., Rapold, C.J., Call, J., Jazen, G. & Levinson, S.C. (2006). Cognitive cladistics and cultural override in Hominid spatial cognition. *Proceedings of the National Academy of Sciences of the United States of America, 103,* 17568-17573.

Hayward, A., McGregor, A., Good, M.A. & Pearce, J.M. (2003). Absence of overshadowing and blocking between landmarks and the geometric cues provided by the shape of a test arena. *Quarterly Journal of Experimental Psychology Section B- Comparative and Physiological Psychology, 56*, 114-126.

Hermer, L., & Spelke, E. (1994). A geometric process for spatial representation in young children. *Nature,370,* 57-59.

Hermer, L., & Spelke, E. (1996). Modularity and development: The case of spatial reorientation. *Cognition, 61,* 195-232.

Hermer-Vasquez, L. Moffet, A. & Munkholm, P. (2001). Language, space, and the development of cognitive flexibility in humans: The case of two spatial memory tasks. *Cognition, 79,* 263-299.

Huttenlocher, J., Hedges, L.V., & Duncan, S. (1991). Categories and particulars – Prototype effects in estimating spatial location. *Psychological Review, 98,* 352-376.

Huttenlocher, J., Hedges, L.V., & Vevea, J.L. (2000). Why do categories affect stimulus judgment? *Journal of Experimental Psychology-General, 129,* 220-241.

Kanwisher, N., McDermott, J. & Chun, M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for the perception of faces. *Journal of Neuroscience,* 17, 4302–4311.

Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science.* Cambridge, MA: MIT Press.

Kelly, D.M. (2005). Use of geometric and featural cues in avian species. Paper presentation at the American Association for the Advancement of Science, Washington, D.C.

Kelly, D.M. & Bischof, W.F. (2005). Reorienting in images of a three-dimensional environment. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 1391-1403.

Kelly, D.M. & Spetch, M.L. (2004a). Reorientation in a two-dimensional environment: I. Do adults encode the featural and geometric properties of a two-dimensional schematic of a room? *Journal of Comparative Psychology, 118,* 82-94.

Kelly, D.M. & Spetch, M.L. (2004b). Reorientation in a two-dimensional environment: II. Do pigeons (*Columba livia*) encode the featural and geometric properties of a two-dimensional schematic of a room? *Journal of Comparative Psychology, 118,* 82-94.

Kelly, D.M., Spetch, M.L., & Heth, C.D. (1998). Pigeons' (*Columba livia*) encoding of geometric and featural properties of a spatial environment. *Journal of Comparative Psychology, 112,* 259-269.

Kersten, D. & Yuille, A. (2003). Bayesian models of object perception. *Current Opinion in Neurobiology, 13,* 150-158.

Learmonth, A., Nadel, L., & Newcombe, N. S. (2002). Children's use of landmarks: Implications for modularity theory. *Psychological Science, 13,* 337-341.

Learmonth, A., Newcombe, N. S., & Huttenlocher, J. (2001). Toddler's use of metric information and landmarks to reorient. *Journal of Experimental Child Psychology, 80,* 225-244.

Learmonth, A., Newcombe, N. S., Sheridan, M., & Jones, M. (in press). Action and reorientation ability: The role of restricted movement at 3 and 5 years. *Developmental Science.*

Lee, S. A., Shusterman, A., & Spelke, E. S. (2006). Reorientation and landmark-guided search by young children. *Psychological Science, 17,* 577-582.

Levinson, S.C. (2003). Space in language and cognition. Cambridge: Cambridge University Press.

Lew, A.R., Foster, K.A. & Bremner, J.G. (2006). Disorientaiton inhibits landmark use in 12-18 month-old infants. *Infant Behavior & Development, 29,* 334-341.

Lew, A.R., Foster, K.A., Bremner, J.G., Slavin, S. & Green, M. (2005). Detection of geometric but not topological, spatial transformation in 6- to 12-month-old infants in a visual exploration paradigm. *Developmental Psychology, 29,* 31-42.

Marcus, G. (2004). *The birth of the mind.* New York, NY: Basic Books.

McComas, J. & Dulberg, C. (1997). Children's memory for locations visited: Importance of movement and choice. *Journal of Motor Behavior, 29(3),* 223-230.

Miller, N.Y., & Shettleworth, S.J. (in press). Learning about environmental geometry: An associative model. *Journal of Experimental Psychology: Animal Behavior Processes.*

Müller, G.B. (2005). Evolutionary developmental biology. In F. Wuketits and F.J. Ayala (Eds.), *Handbook of evolution: The evolution of living systems, Vol. 2.,* (pp 87-115). Weinheim: Wiley.

Newcombe, N.S. & Huttenlocher, J. (2000). *Making space: The development of spatial representation and reasoning*. Cambridge, MA: MIT Press.

Newcombe, N.S. & Huttenlocher, J. (2006). Development of spatial cognition. In W. Damon & R. Lerner (Eds.), *Handbook of Child Psychology, Sixth Edition,* D. Kuhn & R. Siegler (Eds.), *Volume Two: Perception, Cognition, & Language*.

Newcombe, N.S., Jones, M., & Shallcross, W. (2007). How are geometric and featural information used to reorient in a complex space? Part of symposium, "Spatial representation in young children: How is geometric and non-geometric location information processed?" Society for Research in Child Development, Boston, March 2007.

Newcombe, N.S., Jones, M., Shallcross, W., & Ratliff, K.R. (2006, November). Combining featural and geometric information in reorientation. Paper presented at the 47th annual meeting of the Psychonomic Society, Houston, TX.

Newcombe, N. S., & Ratliff, K.R. (2007). Explaining the development of spatial reorientation: Modularity-plus-language versus the emergence of adaptive combination. In J. Plumert & J. Spencer (Eds.), *The emerging spatial mind* (pp. 53-76). New York, NY: Oxford University Press.

Newcombe, N.S. & Uttal, D.H. (2006). Whorf versus Socrates, round 10. *Trends in Cognitive Science, 10,* 394-396.

Pearce, J.M., Ward-Robinson, J., Good, M., Fussel, C. Aydin, A. (2001). Influence of a beacon on spatial learning based on the shape of the test environment. *Journal of Experimental Psychology: Animal Behavior Processes, 27,* 329-344.

Pearce, J.M., Graham, M., Good, M.A., Jones, P.M., & McGregor, A. (2006). Potentiation, overshadowing, and blocking of spatial learning based on the shape of the environment. *Journal of Experimental Psychology – Animal Behavior Processes, 32,* 201-214.

Poucet, B. (1993). Spatial cognitive maps in animals – New hypotheses on their structure and neural mechanisms. *Psychological Review, 100,* 163-182.

Ratliff, K.R., & Newcombe, N.S. (in press). Is language necessary for human spatial reorientation? Reconsidering evidence from dual task paradigms. *Cognitive Psychology.*

Ratliff, K.R., & Newcombe, N.S. (2007). A matter of trust: When landmarks and geometry are used during reorientation. *Proceedings of the Annual Cognitive Science Society, 29,* .

Rieser, J.J., Pick, H.L., Ashmead, D.H., & Garing, A.E. (1995). Calibration of human locomotion and models of perceptual-motor organization. *Journal of Experimental Psychology- Human Perception and Performance, 21,* 480-497.

Rozin, P., & Kalat, J.W. (1971). Specific hungers and poison avoidance as adaptive specializations of learning. *Psychological Review, 78,* 459-486.

Siegler, R. S. (1998). *Children's thinking, 3rd edition*. Upper Saddle River, NJ: Prentice Hall.

Sovrano, V.A., Bisazza, A., & Vallortigara, G. (2005). Animals' use of landmarks and metric information to reorient: Effects of the size of the experimental space. *Cognition, 97,* 122-133.

Sovrano, V.A., Bisazza, A., & Vallortigara, G. (2007). How fish do geometry in large and in small spaces. *Animal Cognition* (online access prior to print publication*).*

Sovrano, V.A., & Vallortigara, G. (2006). Dissecting the geometric module: A sense-linkage for metric and landmark information in animals' spatial reorientation. *Psychological Science, 17,* 616-621.

Spelke, E.S. (2000), Core knowledge. *American Psychologist, 55*, 1233-1243.

Spelke, E.S., Breinlinger, K., Macomber, J. & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, *99*, 605-632.

Spelke, E.S. & Kinzler, K.D. (2007). Core knowledge. *Developmental Science*, *10*, 89-96.

Spencer, J., Thomas, M., & McClelland, J. (in press). *Towards a new grand theory of development? Connectionism and dynamic systems theory reconsidered*. Oxford University Press.

Thelen, E., & Smith, L.B. (1994). *A dynamic systems approach to the development. of cognition and action*. Cambridge, MA: MIT Press.

Twyman, A., Friedman, A. & Spetch, M.L. (submitted). Penetrating the geometric module: Catalyzing children's use of landmarks. *Developmental Psychology*.

Vallortigara, G., Feruglio, M., & Sovrano, V.A. (2005). Reorientation by geometric and landmark information in environments of different size. *Developmental Science, 8,* 393-401.

Vasilyeva, M. & Bowers, E. (2006). Children’s use of geometric information in mapping tasks. *Journal of Experimental Child Psychology*, 95, 255-277.

Wall, P.L., Botly, L.C.P, Black, C.K., & Shettleworth, S.J. (2004). The geometric module in the rat: Independence of shape and feature learning in a food finding task. *Learning & Behavior*, *32*, 289-298.

Wang, H.B., Johnson, T.R., Sun, Y.L. & Zhang, J.J. (2005). Object location memory: The interplay of multiple representations. *Memory & Cognition, 33,* 1147-1159.

Wang, R.F. & Spelke, E.S. (2002). Human spatial representation: Insights from animals. *Trends in Cognitive Sciences*, *6*, 376-382.