THE DEVELOPMENT OF SPATIAL PERSPECTIVE TAKING

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I. Introduction

Piaget and his colleagues invented a multitude of tasks designed both to engage the interest of children and to reveal to curious adults the nature of children's thought. One of the most famous is the "Three Mountains

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Problem," in which children are asked to look at a display of three mountains and to indicate what view would be seen by an observer in another position. Piaget and Inhelder (1948/1967) reported that children made many errors on this problem, up to the age of 9 or 10 years. In particular, when children failed to indicate the observer's true view, they often picked their own view instead.

What does this pattern of performance tell us about children's thought? Both Piaget and Inhelder and subsequent authors, have given a variety of answers to this question. The perspective-taking problem has been most popularly believed to index a global characteristic called "egocentrism," said to be exhibited in many other cognitive tasks, as well as in social understanding. Other writers, however, have regarded the three-mountains task as us about a more restricted part of cognitive development—namely, how children remember the location of objects and what they do with this information. In this article, I argue that Piaget himself made primarily the latter claim.

Section II of this article is addressed to the issue of whether egocentrism is a useful concept, and it contains a review of evidence concerning what young children do understand about "rules for seeing." The section also includes a discussion of the nature of the relationship between development of spatial perspective-taking skills and operative development, in Piaget's theory.

The essential argument of Section II is that the most interesting way to approach spatial perspective taking is to focus primarily on what it can tell us about the encoding and transformation of information about spatial location. Thus, Section III deals with proposals concerning the nature of spatial encoding. Piaget and Inhelder discussed three possible systems for location coding: topological, projective, and Euclidean space. The first was said to precede the second two in development. Criticisms of Piaget and Inhelder's proposal, and alternative ideas about spatial coding proposed by Huttenlocher and Newcombe (1984) are also described in this section.

The longest section of this article is Section IV, a review of the spatial perspective-taking literature, which at this point includes about 100 studies. One purpose of the review is to update an earlier one by Fehr (1978). In addition, however, Fehr aimed essentially to catalogue the variables that influence whether perspective taking, considered as a single variable, appears earlier or later than Piaget claimed. Such a purpose has preoccupied many of the investigators of perspective-taking tasks, but the focus makes sense only on the assumption that perspective taking is a unitary ability, of which an individual can possess more or less. In this article, perspective-taking tasks are regarded as multiply determined. Thus, performance reflects all of the abilities required to perform the task and is revealing only within the context of analysis of the task's requirements. The purpose of Section IV is to analyze the components of perspective-taking tasks, in order to clarify why some tasks are harder than others.

Perspective-taking tasks are not, of course, the only ones that have been used to examine spatial development. Section V considers the most closely related other tasks: (1) allocentric placement, (2) understanding of horizontality and verticality, and (3) mental rotation. The purpose is to examine whether the picture of spatial development gained from perspective-taking problems is similar to that resulting from work with these other paradigms.

Section VI summarizes the conclusions of this article. Specifically, I argue that at least by the age of 5 years, children encode the location of small movable objects with respect to a framework of external landmarks, and that this type of encoding continues into adulthood. Some evidence indicates that children even as young as 3 years of age may encode location in the same way, and it follows that children this young may be expected to succeed at perspective-taking tasks that most naturally involve such a representation.

II. What Does Perspective Taking Assess?

A. EGOCENTRISM

1. Is Egocentrism a Trait?

When children are shown a three-mountains display and are asked about the view of another observer, they pick their own point of view as being that of the other person. The natural inference seems to be a radical inability to identify with the experience of other people. Indeed, Piaget and Inhelder wrote of such performances that "the child fails to realize that different observers will enjoy different perspectives and seems to regard his own point of view as the only one possible" (p. 213).

Children seem to show such focus on the self in other situations as well. For instance, they seem to assume in talking to other people that their partner knows everything they do (*communicative egocentrism*), they have difficulty guessing what other people will feel in certain situations, or imagine others will feel what they do (*affective egocentrism*), and they fail to understand that other people know different facts from those they know (*cognitive egocentrism*). From these separate findings many observers have concluded that through much of middle childhood children suffer from a global quality or trait of egocentrism.

Such a conclusion seems to predict substantial correlations among egocentrism scores in various situations. This prediction has undergone the same vicissitudes that have befallen other hypotheses concerning the existence of traits in human personality (see, e.g., Epstein, 1979; Mischel, 1968). Several recent reviewers have evaluated whether scores on spatial perspective-taking tasks are correlated with scores on measures of egocentrism in other cognitive tasks, as well as in affective and communicative situations (Ford 1979, 1985; Rushton, Brainerd, & Pressley, 1983; Shantz, 1975; Waters & Tinsley, 1985). Ford (1979) concluded that intercorrelations among various measures of egocentrism were low and not always even significant. He proposed that egocentrism be considered only in task-specific terms. Rushton *et al.* (1983) acknowledged that existing correlations were low, but argued that simple psychometric problems with reliability accounted for this fact, and that each type of egocentrism needs to be assessed in multiple ways and aggregated across occasions and situations. Waters and Tinsley (1985) agreed that correlations may be kept low by problems with reliability, and added that existing work had problems with the statistical control of age in mixed-age designs and with the use of scores reflecting total errors rather than egocentric errors per se. They concluded that the hypothesis of cross-domain relationships in egocentrism has simply never been properly evaluated.

Whether future research built on these methodological refinements will provide evidence for a trait-like conception of egocentrism is, of course, unknown. More interestingly for the purposes of this article, however, both sides in this debate have assumed that the existence of a trait of egocentrism is a crucial issue for Piagetian theory. Waters and Tinsley were to some extent an exception, arguing that egocentrism falls into the class of research on individual differences, a topic in which Piaget never took much interest. But the matter goes beyond this point.

2. *The Place of Egocentrism in Piaget's Theory*

Egocentrism was regarded as an explanatory construct in Piaget's early writings (e.g., Piaget 1923/1926), but by the time he worked on space, he had changed this position. Egocentrism had become a descriptive attribute, a characteristic of the early stages of several developmental sequences. It did not, however, serve to explain development, nor did it constitute part of a structural description of thought such that any generality could be expected of it. That is, egocentrism is not like the logic of classes, for example. Any task involving class logic ought to be related, to some extent, to any other task involving class logic, because class logic is part of a structure, is a concrete operational grouping. The same is not true of egocentrism.

A better analogy for egocentrism might be another heuristic principle of development, the cephalocaudal principle. Morphological development in utero proceeds roughly in a head-to-toe fashion, and motor skills in the first year develop roughly in the same fashion. However, one would not thereby expect a fetus to show directed grasping. Nor would one expect even that rate of fetal development would correlate with rate of acquisition of motor skills.

Admittedly, Piaget sometimes wrote as if he believed otherwise. Thus, one can find claims in *The Child's Conception of Space* (1967) such as "it is the egocentric illusion which prevents these children from reversing the left–right, before–behind relations and thereby rotating perspectives along with their changing viewpoints" (p. 218). Nevertheless, in the context of the whole book, such passages seem almost to be asides. Much more weight is given to the perspective task as indicative of understanding of projective space, and the overarching purpose of the book and of the large number of experiments reported in it is to explore the nature of the child's understanding of space. Moreover, as Morss (1987) discusses at length, the evidence available to Piaget did not clearly support the egocentrism hypothesis, and indeed was at least equally compatible with the hypothesis that young children have difficulty understanding the idea of "point of view" at all.

That subsequent writers have concentrated on the issue of egocentrism is understandable, but also regrettable. This concentration has had the consequence that many studies in the literature have been aimed at demonstrating simply that under some suitable set of circumstances, young children do show an awareness that other observers see things differently from the way they do. This point has now been clearly established (see Section II,B). The more important focus in terms of spatial representation is on understanding why children *do* have difficulty dealing with visual perspective taking in some situations where the locations of various objects have to be computed. Information about spatial representation must come from computation tasks, not problems simply requiring recognition that others see something different from oneself.

3. *Egocentrism in Infancy and Childhood*

One of the problems with the term *egocentrism* is that it has had varying definitions both conceptually and operationally. In infancy, egocentrism has been inferred from searching for an object after a change in position has occurred in a way that ignored the change in position. Some writers have concluded that infants represent location only with respect to their own bodies. Debate over this interpretation has been extensive. Presson and Somerville (1985) summarized several problems: Infants' mistakes are at least partly due to the repetition of motor habits rather than to the use of incorrect coding schemes; and correct responding can appear as young as 6 months when landmarks are familiar or salient or when the amount or type of motion is changed (Acredolo, 1979; Acredolo & Evans 1980; Bremner, 1978; McKenzie, Day, & Ihsen, 1984; Rieser, 1979). One possibility for explaining variations in the age at which egocentric responding declines is to postulate that location is always represented with respect to some landmark, including the infant's body, other people in the room, and stable external landmarks. These systems sometimes come into conflict with each other or with motor habits. With age, the infant sorts out which systems are more useful.

Whatever the outcome of this debate about infancy, for the purposes of this article, an important point is that egocentric responding on a search task following movement has not been found at later than $2\frac{1}{2}$ or 3 years (Braine & Eder, 1983). In addition, a variety of studies, reviewed herein shortly, indicate that children know that observers in different vantage points have different views, beginning by the age of 2 or 3 years. Thus, *egocentrism*, as inferred from choices by elementary school children on perspective-taking tasks must mean something different from *egocentrism* as inferred from infants' searching. One possibility is that egocentric choices on a perspective-taking task may indicate nothing specific about spatial coding but rather simply constitute default options in situations where the child is confused (e.g., Aebli, 1967). After all, the child's own view is at least a possible view of the display.

In summary, egocentrism is not a useful term in considering perspective-taking tasks. It is not central to Piagetian theory, with no claims being made for its explanatory value or its place in a structural theory. Furthermore, it no longer has exact meaning, except in infancy, as a hypothesis about spatial coding, and even for infancy, the status of the hypothesis is in some doubt.

B. RULES FOR SEEING

A second view of what perspective taking assesses has been advanced by Flavell and his colleagues. They explicitly divided performance on perspective taking into two areas: (1) rules for knowing what another person sees in general, and (2) computational processes for deciding what that person sees in particular (Flavell, Omanson & Latham, 1978). The Flavell group has concentrated on the investigation of the former domain, that of rules, which they defined as "general relationships among observer positions and observer visual experiences, relationships that are essentially invariant across displays" (Flavell, Omanson, & Latham, 1978, p. 462).

These rules are classified as belonging to either Level 1 or Level 2. Level 1 knowledge concerns inferences about what objects can be seen from another person's viewpoint. At *Level 1*, children know the *that* and the *what* of other people's visual experience, but not the nature of that experience in detail (Masangkay *et al.*, 1974). At *Level 2*, children have acquired rules such as the following: one observer has only one view of an object or array (Salatas & Flavell, 1976), observers in different positions have different views (Flavell, Flavell, Green, & Wilcox, 1981; Flavell, Omanson, & Latham, 1978; Salatas & Flavell, 1976), observers in the same position have the same view (Flavell,

Flavell *et al.*, 1981; Flavell, Omanson, & Latham, 1978), observers in different positions have essentially the same view of homogeneous-sided objects (Flavell, Flavell, *et al.*, 1981) objects that are farther away can be less clearly perceived than ones that are closer (Flavell, Flavell, Green, & Wilcox, 1980), objects appear bigger if they are closer (Pillow & Flavell, 1986), and the orientation of an object to an observer's line of sight determines its projective shape (Pillow & Flavell, 1986).

Absence of Level 1 knowledge is basically the traditional idea of egocentrism. The research of the Flavell group has conclusively demonstrated that egocentrism in this sense simply does not exist, at least not past infancy. Children as young as 2 years will orient a picture or toy so that it can be seen by another observer (Lempers, Flavell, & Flavell, 1977). By 3 years, children understand the essential nature of hiding (Flavell, Shipstead, & Croft, 1978; Hobson, 1980; Hughes & Donaldson, 1979), can easily predict what observers see when they look at the opposite side of a barrier from the child (Flavell, Everett, Croft & Flavell, 1981; Gullo & Bersani, 1983; Masangkay *et al.*, 1974), can infer what observers see from noting their eye position (Masangkay *et al.*, 1974), and know what observers see in displays when what they see is specifiable in terms of discrete features, such as colored spots, or fronts and backs of objects (Masangkay *et al.*, 1974; Verkozen, 1975). When children cover or close their eyes, they may deny that others can see them—not, however, because they do not understand the other's visual experience, but because "see you" means seeing the face region (Flavell, Shipstead, & Croft, 1980).

Level 1 rules can be summarized, perhaps, by the rule that observers see whatever can be connected by a direct line to their eyes. But when all objects in an array can be viewed by observers from a variety of positions, as is true in most perspective-taking tasks, such a rule will fail to predict a unique view. In this case, Level 2 rules become relevant, as does actual computation of other views.

The developmental relationship of acquisition of Level 2 rules to acquisition of the ability to compute is not clear. One hypothesis is that Level 2 rules are prerequisite to some further development that allows successful completion of the standard perspective-taking task. Flavell, Omanson, and Latham (1978) in fact hypothesized that Level 2 rules would be prerequisite to computation. Unfortunately, their data provided little support. Performance on problems solvable only by rule was not correlated with performance on problems solvable only by computation. Importantly for the sequence hypothesis, several children who showed no understanding of Level 2 rules performed perfectly on computational problems.

At what age are Level 2 rules acquired? Salatas and Flavell (1976) found considerable improvement between age 6 and 8 years in understanding of

Level 2 rules. However, Flavell *et al.* (1978) found less evidence of developmental differences with 6-year-olds doing better than they had with the slightly different methodology used by Salatas and Flavell. Subsequent studies have converged on the view that Level 2 rules are acquired at around 4 or 5 years of age (Flavell, *et al.*, 1980, 1981; Pillow & Flavell, 1986). This age seems too early for Level 2 rules and perspective taking to be related, if one assumes perspective taking is difficult until 9 or 10 years. However, perspective taking with item questions (Huttenlocher & Presson, 1979) is a task requiring computation, but it is much easier than the traditional task with appearance questions. Recent evidence shows that children as young as 5 years of age do well with item questions (Newcombe, 1989). Further work will be necessary to determine the ages of first success on these tasks and to compare these data to data on Level 2 rules.
on these tasks and to compare these data to data on Level 2 rules.

In summary, a fair conclusion at present is that by age 2 or 3 years, children know that other observers see different objects from those that they see and that these objects can be inferred by looking across a direct line of sight from the observer's eyes. In this sense, toddlers are clearly not egocentric. By age 4 or 5 years, children have mastered a number of additional rules regarding others' visual experience. The relationship of these rules to the computation of the particular nature of that experience is not clear. One hypothesis—that of Piaget and Inhelder as well as others—is that the ability to compute others' views depends on the nature of children's systems for encoding the location of objects in space. In this view, the acquisition of Level 2 rules would bear no necessary relationship to the ability to solve problems requiring computation.

C. OPERATIVE DEVELOPMENT

Piaget's theory is a stage theory of human development with cognitive development described as progressing through four stages: sensorimotor, preoperational, concrete operational, and formal operational. Critics of the stage concept have focused on the fact that successful performance on the various tasks used to index the stages often does not appear at about the same time in development (e.g., Flavell, 1971; Gelman & Baillargeon, 1983). Perspective taking has not, by and large, figured in this debate, although successful visual perspective taking is often written about as an aspect of operative development (e.g., Brodzinsky, 1982).

Hobson (1982) is one exception: He sought to assess the relationship of perspective taking to concrete operations directly by giving children aged 3 to 7 years tests such as conservation of number as well as perspective-taking tasks. He found that younger children, who failed the concrete operational tasks, nevertheless succeeded on the perspective tasks. However, the perspective tasks were simple Level 1 situations, not necessarily requiring use of projective space. The hypothesis that achievement of perspective-taking skills should occur at the same time as the advent of concrete operations was thus not really tested.

In any case, the hypothesis that perspective taking is an aspect of the development of concrete operations seems not exactly to be something Piaget really claimed. Piaget's thinking about the link between understanding of projective and Euclidean space and concrete operations is fairly complex. On the one hand, he considered the two entities to be fundamentally different. Spatial understanding was characterized as sublogical and different from the logical understanding that was the core of Piaget's theory:

> Concrete operations of a logico-arithmetical character deal solely with similarities (classes and symmetrical relations) and differences (asymmetrical relations) or both together (numbers) between discrete objects in discontinuous wholes independent of their spatio-temporal location. Exactly parallel with these operations there exist operations of a spatio-temporal or *sub-logical* character, and it is precisely these which constitute the idea of space. (Piaget & Inhelder, 1948/1967, p. 450, italics in original)

On the other hand Piaget believed that sublogical and logical systems are related in several ways. The first is that at a formal level, the systems could be considered the same.

> [Sublogical operations] substitute the concept of proximity for that of resemblance, difference of order or position (especially the concept of displacement) for difference in general, and the concept of measurement for that of number. Once expressed in propositional form they are indistinguishable from logico-arithmetical operations, of which they constitute merely a particular species, that of continuity as opposed to discontinuity operations. (Piaget & Inhelder, 1948/1967, p. 450)

Similarly, as the two systems develop, Piaget emphasized the formal parallelisms between them. Thus, much of the final chapter of *The Child's Construction of Space* was concerned with the delineation of the sublogical operations of topological, projective, and Euclidean space, in terms of concepts such as addition of elements and sets and one-to-one multiplication of elements.

Piaget and Inhelder did not, however, hypothesize either an exact formal relationship between concrete operations and the acquisition of projective and Euclidean space, or an exact correspondence in developmental time. Thus, for instance, the first topological grouping they discussed—partition of sets and addition of subsets—was said to be "the exact *equivalent* of class inclusions (A,B,C, etc.) in logic" (Piaget & Inhelder, 1948/1967, p. 463, italics added). For each of topological, projective, and Euclidean space, in fact, they delineated eight operational groupings, with similarities among them but also differences (an example of vertical decalage). They specifically noted the existence of eight concrete operational groupings, writing that "this correspondence is very interesting as regards the functional unity of the various operations of thought" (Piaget & Inhelder, 1948/1967, p. 480). Thus, the use of groupings to describe spatial thought does not appear to imply an empirical relationship between logical and sublogical development.

Piaget and Inhelder did note certain empirical relationships between logical and sublogical development, however. In particular, concrete operational thinking seemed to begin somewhat earlier than understanding of projective or Euclidean space. Piaget and Inhelder hypothesized that topological relations become organized as operational systems at about the same time as operational systems emerge for logical classes and relations, or perhaps a little later because spatial relations are continuous rather than discontinuous. The structuring of topological relations, by the age of about 7, in turn allows rapid development of the projective and Euclidean systems by the age of about 9 or 10.

In *The Child's Conception of Geometry*, Piaget, Inhelder and Szeminska (1948/1981) continued their investigation of spatial development, studying children's ideas of measurement and understanding of the conservation of distance, length, area, and volume. They argued that the construction of Euclidean space is a gradual process accomplished in three stages. The first stage involves the *qualitative* understanding of conservation of distance, length, area, and volume, and the use of transitive reasoning when using one object to compare the size of two others. Only at the second stage does true measurement emerge, but even then, area and volume cannot be calculated. The third stage is not attained until formal operations.

In summary, Piaget's hypothesis of a concrete operational stage has different meanings when applied to content involving classes and relations than when it is applied to spatial content. Spatial content can be topological, projective, or Euclidean; topological content can be structured either intuitively or operationally. Although some aspects of logical development are linked to some aspects of spatial development (e.g., transitivity with a qualitative understanding of measurement), in general, the links between logical and spatial development are more formal than empirical.

III. How Can Spatial Location Be Encoded?

A. TOPOLOGICAL, PROJECTIVE, AND EUCLIDEAN SPACE

Topological space is defined by Piaget and Inhelder as encoding relationships of enclosure, touching, order, proximity, and separation within objects. Another way of defining *topological space* is that it encodes spatial relationships that would be maintained under elastic distortions. It is thus nonmetric.

It fails to distinguish between straight lines and curved ones, and between curves and angles.

Projective space differs from topological space in several ways. First, it does encode relationships among separate objects. Objects are related in terms of straight lines "projected" from one to the other. One of these objects may be the self, in which case objects are linked to the viewpoint of the subject, or one of the objects may be other viewers. Thus, projective space entails the realization that viewers in different positions have different views, as well as the ability to identify the view of each. These abilities are referred to together as the ability to coordinate views or perspectives.

The idea of a straight line is itself a nontopological one. In topological space, which considers only order, straight and curved lines are equivalent. Piaget and Inhelder suggested that the fact that different interpositions of objects are seen when arrays are viewed from different positions is part of how children form the idea of a straight line. Thus, the understanding of points of view and the idea of a straight line are thoroughly interdependent notions. In summary, locations are coded in projective space as falling or not falling on straight lines drawn through specific landmarks or viewing points.

Euclidean space refers to the encoding of spatial location using metric coordinates. Locations are represented relative to an abstract system, rather than relative to each other as in projective space.

An ambiguity in Piaget and Inhelder's writing is whether projective and Euclidean space are "separate but equal," or whether projective space is simpler than Euclidean space and a developmental prerequisite for it. On the one hand, Part Three of their book is entitled "The Transition from Projective to Euclidean Space," and the synopsis includes a discussion of transitional stages between projective and Euclidean space. Later, Piaget and Inhelder noted:

> We have shown that projective concepts imply a comprehensive linking together of figures in a single system, based on the coordination of a number of different viewpoints. But side by side with the development of this organized complex of viewpoints there also takes place a coordination of objects as such. This *leads ultimately* to the idea of Euclidean space, the concepts of parallels, angles and proportion providing the transition between the two systems. (p. 375, italics added)

On the other hand, projective and Euclidean relations were described as being constructed "concurrently" and "side by side," and as being "mutually interdependent" (all phrases on p. 419). Piaget and Inhelder later stated:

> [Concurrent development] is hardly surprising since, on the one hand, a system of reference embraces a view of the whole from a particular viewpoint (remote enough for perspective lines to be parallel). On the other hand, individual perspectives (45°, for instance) are relative to the positions of the observer and the objects, and this the subject can only express by locating them within a total spatial field

> defined by a coordinate system. Whether the first is achieved before the second or the other way round, sooner or later one will inevitably react upon the other. (p. 441)

One might be tempted to conclude that Piaget and Inhelder really meant one or the other of these two apparently contradictory positions. Apparently, however, their accounts of this point involve an unresolved tension. This tension revolves around their preference for Euclidean space as an endpoint of development, in that the achievement of an abstract coordinate system represents the attainment of an understanding of space itself as an absolute entity independent of whether or not it is filled by objects (the "container view" of space). However, even an abstract system, to be useful, must, as they themselves recognized, be anchored in space through the use of certain locations as defining axes or coordinates. Euclidean space uses "certain favored positions as reference points or "points of departure," for all subsequent positions" (p. 376). Thus, the two systems, one absolute and the other relative, are in practice quite similar, and developmentally Piaget and Inhelder believed they are acquired together.

B. CRITICISMS

1. *Terminological*

Two terminological points need to be kept in mind in reflecting on Piaget and Inhelder's proposals about spatial representation. The first is that their usage of *topological*, as pointed out by Mandler (1983), differs from that of mathematicians. The second is that the term *Euclidean* is also infelicitous in some regards, in that Euclidean geometry is not concerned with metrics. Possibly "Cartesian space" would have been a better choice, embodying the idea of coding location in terms of a coordinate system. However, if the definitions given by Piaget and Inhelder are kept in mind, the choice of terminology should not get in the way of a serious consideration of the merits of their theory.

2. *Logical*

The definition of topological space used by Piaget and Inhelder contains a very important problem—whether proximity can really be considered a topological notion. Piaget and Inhelder included proximity on their list of topological concepts (e.g., p. 153). But points being "near" to one another seems to involve some appreciation of metrics, and topological space is supposed to be fundamentally nonmetric.

One way out of this conundrum might be that points are considered proximate if they form units according to the Gestalt laws of grouping. Because topological proximity is defined only within objects, not between them, principles such as common fate would not apply but principles such as similarity might be relevant. This hypothesis would entail predicting that the similarity of elements in a pattern or parts of an object would affect whether or not they were seen as neighbors by young children.

Of course, an alternative is that young children actually are capable of encoding distance in at least a rough way, and that thus proximity does have a metric meaning quite early. We know surprisingly little about the encoding of distance in infancy and early childhood so the question does not have a current empirical answer. (See Newcombe, 1988, for further discussion of the problem of proximity.)

3. Empirical

Topological space, as Piaget and Inhelder defined it, does not distinguish among enclosed areas, so that angular shapes such as squares and triangles are equivalent to circles or ellipses. But as Piaget and Inhelder themselves found, children do make such distinctions, at least by the age of 4 years. Distinctions between curvilinear and rectilinear shapes were also found by Lovell (1959), Laurendeau and Pinard (1970) and Rieser and Edwards (1979).

A second problem with the hypothesis that young children encode space only topologically is that topological space was defined by Piaget and Inhelder as encoding relationships only within objects, but not relationships between them. A large literature, however, indicates that even infants can use between object coding, as when, for example, 9-month-olds use the mother as a landmark for an interesting event occurring to one side of her (Presson & Ihrig, 1982).

The more common interpretation of Piaget and Inhelder has therefore been that topological coding *does* occur between objects, but that the absence of a metric coordinate system leads to great reliance on the presence of landmarks for encoding spatial location. Thus, for instance, Acredolo, Pick, and Olsen (1975) found that younger but not older children remembered the location of an object more accurately with a landmark present, and Herman and Siegel (1978) found that kindergartners but not older children remembered the layout of a model village more accurately with landmarks close by rather than distant.

Huttenlocher and Newcombe (1984, Experiment 1) found, however, that younger children benefited more than older ones from the provision of landmarks only when metric accuracy was considered. Even 5-year-olds in no-landmark conditions showed excellent recall for the *relationship* among a set of objects (i.e., had high configurational accuracy). Thus, young children were able to code spatial location even in the absence of nearby landmarks, but they did so in a rather inexact fashion. At least by 5 years, then, even a relatively weak prediction of the topological space hypothesis is not confirmed.

Somerville and Bryant (1985) and Bryant and Somerville (1986) have shown that 6-year-old children can readily use coordinate systems for encoding location in paper-and-pencil tasks, and that even 4-year-olds' performance is significantly above chance. Their studies were not addressed to the ability to impose an abstract spatial coordinate system, especially in a large-scale space, but they do indicate that the ability to exploit a metric coordinate system is present considerably earlier than Piaget and Inhelder had believed.

Perhaps the most radical questions about the primacy of early topological coding have been raised by Landau (1988; Landau, Gleitman, & Spelke, 1981). The ability of a 2-year-old blind child to traverse novel routes in a simple environment was argued to indicate the innateness of Cartesian space. Methodological questions about this work, however, preclude concluding that children this young use Euclidean space, let alone that such spatial concepts are innate (Liben, 1988).

In summary, several empirical grounds lead to doubt that children, at least by the age of 4 or 5 years, are incapable of coding space in any way other than topological. They appreciate distinctions not recognized in topological space; they code location fairly well even in the absence of nearby landmarks; and they can exploit a coordinate system provided by an experimenter. However, the most radical alternative, that Cartesian space is innate, lacks sufficient evidence to be accepted. Alternative conceptualizations of how location is encoded and how this encoding might change developmentally seem to be needed.

C. ANOTHER MODEL OF LOCATION CODING

Huttenlocher and Newcombe (1984) have proposed a model of the development of location coding with several major steps. At first, the child remembers the location of small target objects only when they are coincident with larger fixed landmarks. (This process is more like paired-associate learning than it is like location coding.) Later, by about 2 years, children remember the location of targets in terms of a rough estimate of their distance from a landmark. Such a coding is likely to be in terms of proximity or neighborhood, a concept which, as noted, is included in Piaget and Inhelder's definition of topology, but which seems fundamentally metric (Newcombe, 1988). A third step is taken by at least 5 years of age, and perhaps earlier, when children appear to use more than one landmark (i.e., frameworks of landmarks) to encode location. This is a much more exact system than using single landmarks. If the framework is constant for all targets encoded (common framework), a framework of landmarks approximates a coordinate system, and an empirical distinction between the two systems may be difficult to draw.

Whether or not common frameworks are used as soon as individual frameworks are used is an empirical question. A logical possibility is that the child at first uses different frameworks for different targets and only later realizes the virtues of using a common framework. Certainly, a common framework is apparently used by age 8, given children's ability at that age to answer spatial transformation questions requiring such coding (Huttenlocher & Presson, 1979). Recent evidence indicates that common frameworks are also present by age 5, again given the ability at that age to answer spatial transformation questions (Newcombe, 1989).

A second issue in spatial coding concerns what Huttenlocher and Newcombe termed "the internal coding of an array of targets"—that is, remembering the relationships among the targets so that the whole is seen as forming a specified shape. In a sense, internal coding involves transforming a set of separate objects into a single object with vertices. Such a coding might make spatial transformation tasks easier, because it might allow all the targets to be transformed as a unit, in a mental rotation process (e.g., Shepard & Metzler, 1971). However, patterns of difficulty on various spatial transformation tasks indicate that neither 8-year-olds nor adults form or use such encodings (Huttenlocher & Presson, 1979; Presson, 1982). Two-year-old children appear to have particular difficulty with internal coding, being unable to utilize it even when it is provided for them by the experimenter (Newcombe, Dubas, & Spies, 1985).

In summary, coding of single targets may develop from association with single landmarks, to proximity to single landmarks, to distance from frameworks of landmarks, with the third stage possibly including a sequence from local to overall frameworks. Internal coding develops more slowly, and is often not used even by adults and even in situations where it would be helpful.

IV. Factors Affecting Success on Perspective-Taking Tasks

This section contains a review of the literature on which factors make perspective taking harder or easier. It is organized into four major sections, dealing with attributes of the subject, the task, the display, and the response mode or dependent variable. The section has two overall aims: first, to summarize what is known about the perspective-taking task in general; and second, to evaluate what variations in performance reveal about spatial representation in particular.

A. ATTRIBUTES OF SUBJECT

1. Intellectual Realism

Piaget and Inhelder's original version of the three-mountains task showed children the mountains so that all were visible from the child's viewpoint, but some mountains were hidden from the viewpoint of others. One reason for selecting or building an egocentric view when the view of another is requested might thus be another attribute of children's thought identified by Piaget, *intellectual realism*: Children may wish to show all the objects they know to be present as present. (However, see Estes, Wellman, and Woolley, Chapter 2, this volume, for some criticism of the concept of intellectual realism.)

The importance of intellectual realism in the perspective-taking performance of children 6 years and younger has been clearly demonstrated (Liben, 1978; Liben & Belknap, 1981; Light & Nix, 1983). For instance, Liben and Belknap found that 3-, 4-, and 5-year-olds had marked difficulty selecting their *own* view when that view showed a large block, behind which children had seen other blocks placed. Thus, investigations of perspective taking using objects that can occlude each other may confound the waning of intellectual realism with the growth of other components of perspective-taking ability. Pillow and Flavell (1985) showed, however, that the problem of intellectual realism may be confined to studies using picture selection as a response made (see Section IV,D) or studies using the expression "looks like" in verbal questioning.

In terms of an interest in spatial representation, an important point is that developmental differences are still found on tasks where only a single object is used (Jacobsen & Waters, 1985) or where the display consists of small objects viewed from above (Huttenlocher & Presson, 1979; Newcombe, 1989), so that no occlusion is involved in perspective taking. Thus, the issue of intellectual realism is in one sense orthogonal to the issue of spatial representation. However, intellectual realism is an important factor to consider in methodology: If one wishes to examine the demand perspective taking makes on representation, at least with younger children, one should use displays that do not involve occlusion. In addition, one must develop a procedure in which children can correctly identify their *own* view, a prerequisite not always met even when displays do not involve occlusion (Gzesh & Surber, 1985).

2. *Cognitive Style*

Two dimensions of cognitive style have been investigated for relationships to perspective-taking ability: field independence and reflectivity–impulsivity. Field independence was found to be associated with better performance on spatial perspective taking by Bowd (1975), Okonji and Olagbaiye (1975), and Finley, Solla, and Cowan (1977), although no association was found by Knudson and Kagan (1977). Reflectivity was found to be associated with better spatial perspective taking at ages 6 and 8 years by Brodzinsky (1980, 1982). In addition, Brodzinsky (1982) found a longitudinal relationship between reflectivity at age 6 and perspective taking at age 8; structural modeling suggested this was consistent with a causal relationship.

Two issues need to be considered with regard to these findings. The first is that the tests measuring field independence (Children's Embedded Figures Test) and reflectivity (Matching Familiar Figures) involve spatial analysis. Thus, the relationship between these variables and spatial perspective taking may reflect that some element of spatial analysis is involved in both tasks, rather than showing that cognitive style as a construct has an effect on the development of perspective taking. Second, even if individual differences in cognitive style as such have an effect on the speed of acquisition of perspective-taking skills, what component of the task is affected is not known. The spatial representation that underlies the ability to solve transformation problems might or might not remain constant. Thus the relevance of cognitive style to changes in spatial representation is not known.

B. ATTRIBUTES OF TASK

1. *Naturalism of Task*

Piaget has often been criticized for using tasks and procedures unnatural to children and therefore underestimating their skills (e.g., Donaldson, 1978). With respect to spatial perspective taking, several specific factors have been mentioned. First, Piaget and Inhelder used dolls to indicate the position of the "other," but dolls are inanimate hypothetical observers that do not really have a view at all. Consistent with this criticism, Cox (1975, 1977a) and Fehr (1979) have found better performance on perspective taking when real people rather than dolls are in the position of the other. Fehr (1979) found that performance with blindfolded people was no better than that with dolls, indicating that the advantage of using people was due to their status as true potential observers of the scene. Thus, using real people as observers facilitates performance. However, it does not eliminate errors or developmental differences, and it seems to be a variable improving performance in general rather than one revealing about developmental change.

A second criticism is that the perspective-taking situation is not sufficiently like a game to motivate children, or not sufficiently familiar for them to understand what their task is supposed to be. Both Hughes and Donaldson (1979) and Hobson (1980) found excellent performance among preschool children with hide-and-seek games. A related criticism is that the usual instructions are not clear enough for young children. Hughes (1978) demonstrated that asking preliminary questions directing preschoolers' attention to critical aspects of a display showing three dolls improved their performance considerably.

Clearly, however, the tasks used in these demonstrations could be solved using Level 1 skills, and they did not require spatial transformation. Thus, the studies add to the forgoing large body of evidence that simple rules regarding what other people can see are mastered early, and that young children are not truly egocentric. They do not, however show that children could succeed on a task with demands comparable to the three-mountains one, if only it were embedded in a more familiar or engaging context.

A third criticism of Piaget and Inhelder's procedure has been that by asking children to demonstrate their own view first, experimenters increase egocentrism by suggesting to children who are perplexed by the problem that their own view is an acceptable answer. Indeed Aebli (1967) and Garner and Plant (1972) have shown that children not asked first about their own view make fewer egocentric errors. Interestingly, however, Aebli did not find a decreased number of total errors (and Garner and Plant did not test this). Thus this aspect of the procedure increases the proportion of errors that are egocentric, and the fact that the proportion can so easily be diminished suggests that the answer is, as Aebli put it in his title a "substitute solution for an insoluble task." But why the task is so difficult remains unexplained.

A fourth class of variables investigated by those interested in the real-world context of these problems involves whether children's performance is better when they are first allowed either to play with the materials or to interact with them together with other children of either the same or different cognitive levels. Matthews, Beebe, and Bopp (1980) found a small facilitative effect of play with materials on perspective taking, although it may not have been statistically significant. Doise, Mugny, and Perret-Clermont (1975) and Mugny and Doise (1978) found better performance on an allocentric placement task (see Section V,A) following experience working with a partner on the problem, but this finding was not replicated by Bearison, Magzamen, and Filardo (1986) for perspective taking. Bearison *et al.* did, however, find better performance at least among boys who experienced a moderate amount of sociocognitive conflict in the dyads. This research at least suggests that play, either solitary or interactive, may be helpful to cognitive growth. However, even if true, we would need to specify what was being acquired. In particular, the research does not deal with whether or not play and social interaction lead to the development of more sophisticated systems of spatial coding or transformation or to more efficient or consistent use of existing systems.

In summary, increasing the naturalism of the task does, in some cases, lead to better performance, or at least to reduced egocentrism. However, the research in this tradition has not been focused on process, and some experiments have involved Level 1 tasks rather than tasks requiring computation. Thus, how the naturalism of the task affects spatial coding has not been assessed and the studies do not necessarily show that younger children can encode and transform spatial location in the same way as older children, given natural tasks.

2. *Shielding of Display*

Several researchers have tested the hypothesis that shielding the display from view when children are asked to select the other's view would enhance performance, presumably by reducing distracting perceptual cues. Brodzinsky, Jackson, and Overton (1972) found improved performance, at least on multiple object arrays, for 8- and 10-year-olds, but not 6-year-olds. They suggested that shielding did not help the younger children because they had no underlying understanding of the problem that could be activated in the right circumstance. Walker and Gollin (1977) found that shielding reduced the incidence of egocentric errors for 4-year-olds but not 7-year-olds on a single-object task. Shielding did not reduce total errors, however; it simply changed the type of error. These two studies suggest that shielding the array may improve performance at least for certain arrays and ages, using developmentally appropriate dependent variables. Age trends remain, however, within the shielded conditions, indicating that perceptual distraction is but one source of age differences on this task.

The evidence, in any case, is not uniformly positive. De Lisi, Locker, and Youniss (1976) failed to find an effect of shielding, also using multiple-object arrays and the same age groups as Brodzinsky *et al.* Flavell, Botkin, Fry, Wright, and Jarvis (1968) did not find that having children turn away from the array before answering improved their performance, although this might be because turning away not only removes the array from view but also introduces a distracting rotational component to the problem. Most problematic is that Huttenlocher and Presson (1973) actually found the opposite effect: Shielding the array led to worse performance. They suggest memory demands were increased when the array was not visible.

In summary, the effect of shielding is most likely a complex one. It may be helpful to certain age groups, but probably only when the tradeoff in terms of extra memory demands is not too severe.

3. *Experience with Array from Different Viewpoints*

Eiser (1974) noted that some investigators allow children to walk around the display before being asked questions, in which case the questions may tap children's memory for the various views, as well as their ability to infer the views. Her own study of 7-year-olds showed that walking once around the array led to a slightly smaller number of egocentric errors than shown by an inference group but no significant reduction in overall errors. More experience might of course lead to more marked effects. But one would have to be careful not to design a task that assesses memory, which would not be relevant for understanding spatial transformation.

4. *Actual versus Imagined Movement*

The classic perspective-taking task involves spatial inference, with the subject remaining in one position but attempting to construct the view from another. Several researchers have asked what performance would be like if subjects were asked to move to another position, of course with the array covered so that the answer would not be self-evident. The evidence seems quite clearly to indicate that physical movement makes the task much easier. Shantz and Watson (1971) found excellent performance by 4-, 5-, and 6-year olds on such a task; the same subjects, however, had great difficulty on classic perspective taking. The same results were obtained by Huttenlocher and Presson (1973), testing 9-year-olds, and Schatzow, Kahane, and Youniss (1980), testing 8- and 10-year-olds. More recently, Huttenlocher and Newcombe (1984, Experiment 2) showed that even 2-year-olds could locate an array of objects correctly after moving to the opposite side of a board, as long as spots marked the correct vertices of the array.

Why are objects so easy to locate correctly after actual physical movement, and so difficult when the movement must be imagined? Huttenlocher and Newcombe (1984) suggested that the reason may be that locations of objects are typically coded in relation to a framework of external landmarks. When the subjects move, they change their relation to that framework, so that the location of the targets becomes perceptually obvious and minimal inference is involved.

5. *Availability of Outside Landmarks*

Given the argument in the preceding section, perspective taking should be better when external landmarks are available than when they are not. Unfortunately, no existing study has tested exactly this hypothesis. Fehr (1980), Fehr and Fishbein (1976), Huttenlocher and Presson (1973), and Lapsley, Fehr, and Enright (1981) all found better performance when an additional landmark was added, presumably with background landmarks in the testing rooms always present. The nature of the added landmark is not clear in the latter three reports; Huttenlocher and Presson used a horse in a fixed position facing the array. P. L. Harris and Bassett (1976, Experiment 1) failed to find an effect of including a small shell as a landmark on the child's board in a model-building task.

Presson (1980) conducted the most direct test of the hypothesis that locations in the target array are usually coded with respect to the wider spatial field. He compared perspective-taking performance under standard conditions and performance under a modified condition in which children observed a model of the experimental room, oriented as it would be seen by the hypothetical viewer. This cue improved the performance of 7-, 9-, and 11-year-olds. It also decreased egocentric errors for 90° and 270° movement, although not for 180° movements. Thus, the evidence clearly indicates that through middle childhood, the spatial locations of subjects in perspective-taking arrays are coded with respect to external landmarks.

6. *Amount of Movement*

Investigators have generally compared the difficulty of imagining an observer on the opposite side of the array (180° movement) with the difficulty of 90° and 270° movement, although some work has included other positions as well. Some researchers have speculated that 180° movement might be *easier* to imagine than other amounts, for one of several reasons. When fronted objects are used in the array, and shown facing the child in the 0° position, recognizing the fronts and backs of ths objects may be easier than recognizing the sides (Gzesh & Surber, 1985). In addition, when objects are shown so that movement results in varying degrees of occlusion and interposition, recognizing the reversal of what is visible or hidden at 180° may be easier than recognizing the differences as seen from the side views (although this argument is at odds with the intellectual realism argument). Finally, the reversal of dimensions at 180° (front-back and left-right reversal) might be easier to compute than the cross-dimension changes occurring at side views (left becomes front, front becomes right, etc.).

Other investigators have hypothesized that 180° movement should be *harder* than all other conditions, for one of two reasons. If one believes that subjects reposition themselves or locate the other observer by continuously tracking a path from their current position in their "mind's eye" and that they take the shortest route to do so, going either left or right, depending on the distance to the target location, then 180° represents the greatest distance traveled, and errors might increase with distance. Another idea focuses on the fact that dimensions remain constant at 180°, but suggests that reversal is confusing for subjects rather than facilitating.

Some studies have shown 180° movement to be easier than other amounts of movement (Eiser, 1974; Gzesh & Surber, 1985; Presson, 1982, Experiment 2; Rosser, Ensing, Mazzeo, & Horan 1985, rotation task), but other researchers have found significantly greater errors at 180° (Cox, 1977b; Fehr, McMahon, & Fehr, 1982; Nigl & Fishbein, 1974). Jacobsen and Waters (1985) found a trend for more errors at 180° for a task involving the position of a single object.

The conservative conclusion to this controversy is that difficulty does not systematically vary as a function of observer position. The number of studies showing effects each way is roughly the same. Other researchers found no significant differences (Bialystock, 1986; Borke, 1975; Cox & Willetts, 1982;

Presson, 1980, 1982, Experiments 1 & 3; Rosser *et al.*, 1985, construction task; Schachter & Gollin, 1979; Shantz & Watson, 1971). Many other researchers did not report data separately by observer position, and at least in some cases, this omission may be because preliminary analyses showed no differences. From a theoretical point of view, the reasons given for the putative ease or difficulty of 180° movement seem contradictory and post hoc.

7. *Training*

Most Piagetian tasks have been the subject of extensive efforts to train better performance in young children, thereby obtaining clues about what experiences they lack or what hidden competencies they have. Perspective taking, for no apparent reason, has been an exception, but some attempts have been reported. Miller, Boismier, and Hooks (1969) found a modest improvement in perspective-taking performance in 7-year-olds, following six individual lessons on sighting, transformations along left–right and near–far dimensions, and practice on perspective tasks of graded difficulty. Cox (1977c) found that 5-year-olds showed delayed as well as immediate improvement on perspective and related tasks, following 20 individual training sessions on tasks of gradually increasing difficulty, with verbal feedback from the experimenter and movement by the child to check responses. An especially notable feature of Cox's study was the very high performance levels reached and maintained by the young children.

Both Cox and Miller *et al.* developed training programs dealing with as many components of perspective taking as possible. Silverman (1986) found significant improvement in perspective taking for 6-, 8-, and 10-year-old children following simple feedback on the correctness of answers, including better performance on delayed tests and transfer tests. This finding suggests that at least part of children's difficulty may be simple lack of understanding of the procedure. That this problem is not the whole story, however, is shown by the fact that performance, especially on transfer tests, was still far from perfect, as well as the fact that age differences persisted within conditions.

Perhaps the most interesting aspect of Silverman's study from the point of view of spatial representation lies in the fact that instruction in coding the array failed to improve performance, and in fact, when feedback was absent, actually seemed to hurt performance. The instructions emphasized coding the array as a unit, something subjects apparently rarely do and may find difficult (Huttenlocher & Presson, 1979; Presson, 1982). Kielgast (1971) also found that having children verbally describe the internal relationships of array items was not helpful to, and not correlated with, their performance on perspective taking. It would be interesting to see if instructions emphasizing locating objects in relation to the external framework would improve performance on tasks such as item questions for which this coding is an asset (Huttenlocher & Presson, 1979).

In summary, perspective taking appears to improve following training, but training studies to date have not been analytic regarding the components of the task being taught. We need to know what specific skills or coding schemes children most need instruction in, and whether these apparent lacks are the same or different at different ages.

C. ATTRIBUTES OF DISPLAY

1. Characteristics of Objects

The objects composing the visual display shown in perspective-taking tasks may be familiar or unfamiliar to the child, may be symmetric or have canonical fronts, may vary or not vary among themselves in perceptual characteristics such as height or color, and so on. In addition, the objects may be arranged in symmetric patterns with respect to each other (squares, triangles, circles) or be arranged asymmetrically; if the objects are meaningful and familiar to children, arrangements may be themselves meaningful (e.g., barnyard scene) or not. Surprisingly little parametric research exists on the effect of such manipulations on perspective-taking ability despite the frequency of speculation on the subject. Thus, for example, the difficulty even 11- or 12-year-old children had with some of Laurendeau and Pinard's (1970) tasks is often attributed to those researchers' use of symmetric, unmarked objects in displays, but no systematic comparisons support this commonsense argument.

a. Familiarity. Familiarity has not been investigated in a fashion unconfounded with symmetry. Borke (1975) found that when the display involved familiar fronted objects such as animals and houses, 3- and 4-year-olds had less difficulty indicating the other's perspective with a model rotation device than with Piaget and Inhelder's mountain display. This finding was obtained even when the number of familiar objects was much greater than three. However, the familiar objects were fronted, and the mountains were not (except that a small house appeared on one mountain).

A similar comparison made by Rosser *et al.* (1985) yielded different results. They used either animals or vehicles (objects that are both familiar and fronted) for their "marked" displays and rectangular solids and circles for their "unmarked" ones. (Number of colors and arrangement of objects were also confounded with "marking" in this study.) Rosser *et al.* found no difference between the two display types when children used a model rotation device, in contradiction to Borke. (In addition, when the task was model construction, the familiar fronted objects were *less* accurately placed than the geometric solids, but this comparison is flawed by the fact that children's placements were scored by different criteria in the two conditions: marked objects had to be oriented correctly as well as to occupy the correct position to receive a point.)

Thus, although familiar objects may well be easier to encode and transform, for reasons having to do with motivation or perceptual differentiation or both, comparisons are needed that unconfound familiarity with symmetry before this point can be accepted.

b. Orientation. The work of Borke and Rosser *et al.* just discussed deals with frontedness of objects as much as with familiarity. One might assume that symmetric objects would be harder to deal with in perspective taking then fronted ones because symmetric objects might be confusable with each other. However, reflection suggests that the influence of symmetry depends on the response required. If the correct choice from a given point of view must be selected from a set in which all choices preserve the internal structure of the display, then having fronted objects may well be advantageous. Given fronted objects, a child may be able to choose correctly by attending to one specific feature—figuring out, for instance whether the horse would be seen head on, back on, or side on by another observer. In this case, of course, the child is not really required to consider the spatial location of the objects or to transform the locations, and thus this task does not assess issues of location coding at all. If the child must consider orientation as well as position in making a response, however, as is required when reconstructing a scene from another's perspective, then the use of fronted objects may make the task more difficult.

Encoding the orientation of objects has been studied as a topic in its own right. L. J. Harris and Strommen (1972) found a high degree of consensus among 4- to 7-year-olds in their interpretation of directions involving "front," "back," and "beside." This was greater for featured objects, but still considerable for featureless (symmetric) objects. Subsequent research has shown that children as young as 2 years have acquired the concepts of front and back, even when they have not mastered the linguistic terms (Levine & Carey, 1982). Thus, children can encode orientation early, but less is known about the development of the ability to mentally transform orientation.

Encoding the orientation of objects in perspective-taking tasks has been studied by Coie, Costanzo, and Farnill (1973) and Eiser (1976). Coie *et al.* conducted analyses of the kinds of errors made by children from ages 5 to 11 years on picture choice tasks. They concluded that children are able to transform orientation (which they called "aspect") by age 10, but that children of this age still have difficulty with position on the right–left dimension. Thus, by implication, they supported the foregoing argument that featured objects would enhance performance on perspective-taking tasks in which figuring out the correct orientation of at least one object allows correct choice, but that such choice does not necessarily assess the ability to transform spatial location and to infer position.

The data of Eiser (1976) also suggest that orientation and position of fronted objects may be attended to differentially, although they initially seem to undercut the argument that orientation information can be used to enhance performance on perspective-taking tasks by allowing position to be ignored. Children of 8, 10, and 12 years had to guess what an experimenter hidden from them was seeing by asking her questions. Questions were coded as regarding either the orientation of one of the three objects (two were fronted) or as regarding their position. Success at guessing the perspective of the experimenter was greater when position questions were asked, and less with orientation questions. Of course, children themselves selected their questions, so less cognitively advanced children may have concentrated on orientation questions and more advanced children on position questions. It would be interesting to know how children would respond in a guessing paradigm where hints of each kind were supplied by an experimenter. In this case, orientation information might be more helpful than position information, or helpful at younger ages.

c. Other Characteristics. Fehr, Lapsley, Enright, McMahon, and Ackerman (1983) noted that perspective-taking tasks often require that children recognize three-dimensional displays from two-dimensional pictures. The mapping from three to two-dimensional stimuli might be a source of difficulty. Their data indicated that, indeed, when two-dimensional arrays were presented, subjects from 7 years of age through college showed better performance than they did with three-dimensional arrays. Children of 5 years were at low levels of performance overall. Strong age trends were present, however, within each condition, with little indication of age-related interactions, except for the floor effects with 5-year-olds. Thus dimensionality crossing does not seem to be a major confound in developmental investigations of perspective taking.

Similarly, Eliot and Dayton (1976) found that board shape, block arrangement, and block shape had effects, some of them in complex interactive fashion, on the difficulty of perspective taking. These effects were apparent for subjects from 6 years of age through college, with no trace of age-related interactions. Thus developmental investigators are free to choose board shapes and block arrangements without fearing that the difficulty level set by these decisions will be different for different ages.

2. *Number of Objects*

At first thought, increasing the number of objects in the array seems likely to increase the difficulty of the task; more locations would have to be encoded and transformed. For construction tasks, increasing the number of objects has this effect. Rosser *et al.* (1985) have confirmed that children aged 6 and 8 years have more difficulty reconstructing four, as compared to two-object arrays.

For picture-selection tasks, however, number of objects should not, logically, affect performance, because working out the position of any one item allows for correct choice unless the choices include scramblings of the internal arrangement. Similarly, performance of model-rotation tasks should not depend on number of objects in the array. Fishbein, Lewis, and Keiffer (1972) found, however, that performance was better for one object than for three objects on both a picture-selection task (Experiments 1 and 2) and a model-rotation task when ceiling effects were avoided (Experiment 2). The advantage of single objects did not vary in size with age across the range of 3 to 9 years; thus, even older children did not realize that the three-object condition was logically reducible to the single-object condition. Gzesh and Surber (1985) also found better performance for one than for three objects in a picture-selection task.

Several other studies, however, have failed to yield an effect of number of objects in the array on the accuracy of picture selection (Brodzinsky *et al.*, 1972; Liben, 1978; Minnigerode & Carey, 1974; Nigl & Fishbein, 1974). Brodzinsky *et al.* did, though, apparently find an advantage for single-object over multiple-object arrays in their unshielded condition.

One reason that has been suggested for some of the failures to find an effect of number of objects is a threshold effect. Neither Liben nor Nigl and Fishbein included a single-object condition, and Minnigerode and Carey studied the effect of having one, two, or three landmarks on the slopes of an ever-present mountain. Once the number of objects in an array is two or more, Nigl and Fishbein argued that children may attempt to encode internal spatial relationships. The addition of a third object then provides only redundant information, and does not increase the number of spatial relationships to be encoded. This explanation is puzzling, however, in that it attributes to children a strategic appreciation of redundancy, exactly what would seem to be lacking in the failure to concentrate on the location of a single item in all cases.

The idea that single-object arrays are relatively easy is challenged by the findings of Jacobsen and Waters (1985). They used a symmetrical tower as a stimulus, and found 7-year-olds having error rates as high as 68%. This contrasts with 41% errors made by 6-year-olds and 26% by 8-year-olds in the most analogous single-object condition in the Fishbein *et al.* study. The difference between the studies raises the possibility that the results of Fishbein *et al.* and Gzesh and Surber, and the partial replication by Brodzinsky *et al.* depend on the use of fronted objects. The easiness of their single-object conditions seems likely to be predicated on the fact that success can be achieved by noticing whether another observer would see the front, or back, or a particular side feature of a differentiated object. This does not require the encoding or transformation of information about spatial position. This hypothesis still leaves as a mystery the question of why children as old as 9 years are nonstrategic in dealing with orientation information; they do not simply work out the orientation of one object, but appear to try to deal with several or all of the objects in multiple-object arrays.

When position information must be processed, as when objects are symmetric, increasing the number of objects may not increase difficulty. No such effect was found in studies by Liben, by Minnigerode and Carey, and by Nigl and Fishbein; Jacobsen and Waters found that a single-object task was quite difficult, even though they did not specifically compare performance to that in a multiple-object condition. Thus, in position tasks, children may in fact concentrate on the position of a single object, with the addition of other objects not increasing the difficulty.

3. *Near–Far versus Left–Right*

Piaget and Inhelder noted that children in transitional stages seemed to be able to work out what positions would be near to or far from another observer before they could work out what positions would be to the left or right. They attributed this difference to the fact that "intuitively—which is to say, egocentrically—there is a bigger difference between a background beyond the reach of immediate action and a foreground directly subject to it, than there is between a left and right which are equally near or distant" (p. 235).

Several subsequent studies have confirmed the greater difficulty of left–right relationships as compared to before–behind ones (Coie *et al.*, 1973; Cox, 1978a, 1978b; Liben, 1978; Nigl & Fishbein, 1974). This difference is present when only one dimension must be considered at a time, as well as when both must be considered simultaneously (Hoy, 1974; Minnigerode & Carey, 1974). Furthermore the difference is not reducible to general left–right confusions (Liben, 1978), which, in any case, may have been overestimated (e.g., Braine & Eder, 1983).

All the studies confirming the greater difficulty of computing left–right relationships, however, involved arrays that, like the three mountains, contain interposition. In this case, correct choices on the before–behind dimension involve knowing what will be hidden and what will be visible from a given position, rather than simply being able to work out relative spatial position. When this factor is eliminated, the difference apparently disappears. Cox and Willetts (1982) eliminated interposition by using flat arrays, and Jacobsen and Waters (1985) by using a single object. Neither study indicated a special difficulty with left and right.

In summary, children initially have a preference for showing all objects as visible, but by age 7 or so they are able to predict accurately what objects will be visible from a specified position and what objects will be hidden. This ability is not, however, due to the practical difference between being able to reach an object or not (near vs. far), as shown particularly clearly by Jacobsen and Waters. Children may have difficulty on certain tasks with *both* left-right and near-far positions, when interposition is avoided, at least until the age of 9 or 10 years.

D. RESPONSE MODE

Piaget and Inhelder reported data on three tasks: model building, picture selection, and placing of a doll to indicate the position from which a specified view could be seen. Their discussion emphasized the similarities in findings using the three tasks. Subsequent researchers have largely ignored the doll-placement task, although Miller (1967) and Laurendeau and Pinard (1970) have confirmed that the approximate ages at which it is mastered correspond to those for picture selection, with doll placement possibly somewhat easier. Investigators have, however, added several new response paradigms to the original three, as well as exploring the effect of variations in the type and number of choices in the picture selection task.

1. Surprise Paradigms

Shantz and Watson (1970, 1971) showed that children as young as 3 years gave verbal and facial indications of surprise when, after moving to another position around a covered array, they were shown the same array they had originally seen rather than a different one. This surprise shows, of course, that they expected to see something different from their first view, and thus that they are not egocentric; they know that different observers have different views. This research fits well with research reviewed earlier showing that young children are not fundamentally egocentric. Further, it suggests that, at least when children actually move to a new location, they understand a Level 2 rule, in Flavell's terminology (i.e., different positions, different views) by the age of 3. However, the surprise paradigm does not allow for any assessment of what children expected to see in particular, and so it does not bear on issues of spatial representation.

2. *Model Rotation*

A second response paradigm on which younger children show considerable success at perspective taking is a model-rotation task. Children are asked to turn a model or duplicate of the array to indicate what would be seen from a specified position (or, in a study by Fishbein *et al.*, 1972, to show to a person who is in a certain position a view of the display, as shown in a picture). Borke (1975) showed that children as young as 3 or 4 years performed surprisingly well on this task, even achieving 42% and 67% correct responses respectively, on a three-mountains display. Borke did not specifically compare these data to those obtained with another response mode, but the superiority of model-rotation to construction tasks has been shown by Rosser (1983) and Rosser *et al.* (1985), and the superiority of model rotation to picture-selection tasks has been shown by Fishbein *et al.* (1972) and Horan and Rosser (1983).

From the point of view of spatial representation, the important aspect of model-rotation techniques is that the device itself preserves the internal spatial relationships among the objects in the array. Thus, the child needs to be able to infer only which object will be nearest an observer after a specified degree of movement. This inference they can evidently make. Piaget and Inhelder in fact noted the same phenomenon although not at ages as young as those studied by subsequent investigators.

A question arises concerning why model rotation is easier than picture selection on this analysis, when most picture-selection tasks, including those of Fishbein *et al.* and Horan and Rosser, include only pictures of *possible* views of the array. That is, the pictures from which the child must choose do not include internal rearrangements of the elements, and successful choice is possible if the child can infer what object will be nearest the hypothetical observer. Several relevant factors, however, probably increase the difficulty of picture selection over model rotation. First, picture selection requires the child to scan and compare a set of similar pictures, something young children are known not to do efficiently or exhaustively (e.g., Vurpillot, 1968). By contrast, in model rotation, the child has to look only at a single array. Second, model rotation gives the child an opportunity to see the array transformed in a continuous fashion, which may help in imagining spatial transformation. By contrast, picture selection only shows the discrete static outcomes of spatial transformations. Third, the model-rotation task encourages the child to treat the task as one of array rotation rather than observer movement and the former has been shown to be easier than the latter even when picture selection is used for both (Huttenlocher & Presson, 1973). Fourth, the model-rotation device may allow the child to engage in more experimentation and trial and error, but the demand characteristics of the picture-selection task are such that a child may feel the need to point to a picture and stay committed to that answer. In summary, the fact that rotation devices preserve the internal structure of the array for the child is important from the spatial representation viewpoint, but several other aspects of the paradigm probably also contribute to children's early success with it.

3. Picture Selection

Picture-selection tasks are the most widely used technique for studying perspective taking. As suggested, however, they have demands of their own, some of which may increase the difficulty of showing the correct perspective. First, pictures are two-dimensional representations of a three-dimensional array. Nigl and Fishbein (1974, Experiment 3) have shown that offering a choice of three-dimensional models rather than pictures leads to better performance for both 6- and 10-year-olds. The advantage of models appeared for both the younger and the older children in conditions where ceiling and floor effects were avoided.

A second fact about picture selection is that it requires the scanning and comparison of similar pictures, something younger children might be expected to find more difficult than older ones. In fact, increasing the number of choices seems to make the task harder, although this effect may not be differentially marked for younger subjects as one might expect. Fishbein *et al.* (1972) studied the ways that having four or eight response choices affected 4-, 6- and 8-year-olds. They found that increasing the number of choices decreased accuracy, but that this effect was as marked for the older as for the younger children. Salatas and Flavell (1976) found no difference in number correct between a seven-item and a nine-item answer set, for 6- and 8-year-olds, but they did find more egocentric errors for the larger set. Age differences in this tendency were not reported. Thus, research to date indicates that increasing the number of pictures to be examined decreases performance in the age range from 4 to 8 years. No age-related interactions have emerged, however, suggesting that a greater number of choices is a special problem for the younger subjects, one which might mask their true spatial abilities. However, more research, using a greater variety of ages and numbers of pictures might show such an effect.

A third fact about picture selection, discussed by Huttenlocher and Presson (1979), is that the selection must be made with the pictures in the same room as the array, and thus with the items in the array shown in incorrect relationship to the landmarks in the room. If the items have been encoded using the landmarks as suggested by the work of Presson (1980), this kind of incorrect relationship might be confusing.

A last aspect of most picture-selection tasks is one that should make the task easier rather than harder. Many researchers present as choices only views of the array that are actually possible. That is, they do not show views of scrambled or rearranged arrays. Thus success is possible if children can compute the relationship of only one object to the observer correctly, perhaps what object would be nearest the observer, as originally suggested by Piaget and Inhelder. Work by Cox (1978a, 1978b) and Bialystock (1986) indicates the importance of this factor. These investigators included among the response choices pictures showing the nearest object to the observer correctly, but other objects in rearranged order. Children up to the age of 9 or 10 years were quite likely to choose the scrambled picture. Thus, picture-selection tasks preserving the internal structure of the array probably overestimate the ability of younger children to solve spatial transformation problems in that they allow for success on the basis of ability to compute which object would be nearest an observer, without a need to transform the positions of the other objects. The data also indicate that at least until the age of 9 or 10 years, children do not encode the internal structure of the array, but rather consider the position of each object separately. Adults may also fail to encode the internal structure of the array (Presson, 1982) but what they may do, unlike younger subjects, is to check additional objects to see if the picture they have chosen is the correct answer.

4. Model Building

Piaget and Inhelder reported similar results for model building as for picture selection. Subsequent work has shown that building appears to be harder overall than picture selection (Hoy, 1974) as well as harder than model rotation (Rosser, 1983); but has confirmed that very similar *patterns* of results appear for model building and picture selection (Hoy, 1974; Presson, 1982).

Model building has two advantages as a dependent variable. One is that it is helpful in studies of adults who make few errors on other tasks (Presson, 1982). A second is that it allows inferences about mental processes to be made from examination of the order of placement of the elements (P. L. Harris & Bassett, 1976). In particular, Harris and Bassett noted that children as young as 4 years generally position first the element of an array that would be closest to an imagined observer even when they then continue to build the array so that the finished product shows an egocentric view. This ordering suggests that subjects as young as 4 years can imagine the position of the other and compute what object would be closest to the observer's position. They may have difficulty, however, in working out the relationships of any other elements to the observer and thus fall back on an egocentric response. Alternatively, they may be overwhelmed as they build by the fact that they are asked to position targets within the same framework of external landmarks with respect to which they coded the original positions.

5. Item and Position Questions

Huttenlocher and Presson (1979) contrasted the performance of 8-year-old children on a model-selection task (appearance question) with their ability to answer questions about which item would be in a specified position after a specified degree of observer movement (item question). That is, on the item question, children were asked which of four objects would be close to them (or far away, or on their left-"red" side or right-"green" side) if they were seated at other positions around the array. Answers to these questions were 80% correct, and answers to appearance questions were only 44% correct. The better performance was not due to ease of understanding the question per se, because when children were asked to imagine the array moving on its own axis, rather than the observer moving, item questions were actually harder than appearance questions (see below). Nor was the ease of item questions due to their focus on one element of the array at a time, because position questions (if a viewer were at a specified point, where would a particular object be?) are much harder (Hardwick, McIntyre, & Pick, 1976; Presson, 1982)

The best way to explain the ease of item questions seems to be that the locations of items in the array are coded individually with reference to the external landmarks in the room. When the hypothetical observer is also located with respect to this framework, the relations between objects and the observer can be read from this representation. In contrast, selecting a model to show the observer's view requires the child to ignore a model (the egocentric choice) showing the targets in their correct relationship to the external framework, in favor of a model showing the targets in an incorrect relationship to this framework. Presson (1987) presents an extended discussion of data of this kind, using the concepts of primary and secondary uses of spatial information. He argues that picture selection requires the use of an abstract, secondary frame of reference rather than the primary frame of reference (the room). The ability to perform such secondary analysis is said to develop with age, rather than the abilities to encode objects or perform mental transformations.

Thus, by the age of 8 or 9 years, children seem to code spatial location in a fashion sufficient to allow them to compute the location of objects relative to an observer in another position. Furthermore, the fact that adults show similar patterns of performance (Presson, 1982) suggests that no developmental change in spatial encoding occurs after this age. However, 8 or 9 years is close to the 9 or 10 years at which Piaget and Inhelder believed that children develop understanding of projective space. A crucial question thus becomes whether younger children also show good performance on item questions. Newcombe (1989) has demonstrated that 5-year-olds also do well on item questions while showing the usual difficulty with appearance questions.

Even younger children may be able to answer item questions successfully. P. L. Harris and Bassett (1976) found that 4-year-olds in a model-building task place first the object nearest a hypothetical observer which implies the ability to work out at least one observer-object relationship. Ives (1980) using a single object (house, horse) as a stimulus asked children to say whether they would see its front, back, or side from a specified position (a single-object analogue of an item question). Responses were about 90% correct even among 3-year-olds; picture selection, however, was much more difficult. How preschool children would perform in answering item questions concerning a multiple-object array is of course unknown.

E. SUMMARY

Of the many variables reviewed in the section, some do not appear to show a relationship to perspective-taking performance. These include shielding of the display; the relative difficulty of 90°, 180°, and 270° movement; the number of objects in the display (when position information must be processed); and near–far versus left–right (when interposition is avoided). Relationships of other variables to perspective-taking have not been clearly assessed. These include motivational context, clarity of instructions, and familiarity of objects.

A relatively large number of factors has been identified that do make perspective taking easier or harder. However, not all bear on the issue of how children code location and whether this coding is different from that of adults. Children of age 6 years and younger have difficulty with displays involving occlusion, because they wish to show all objects they know to be present as being present. Children who are generally good at spatial analysis may solve perspective-taking problems more easily. Perspective taking is easier (or at least less likely to be egocentric) when people are used as others rather than dolls, when children are not asked to show their own view first, when children first play with the materials or work with them in groups, when children walk around the display before being asked questions, when children are given training, and when displays do not differ from answer choices in dimensionality. However, none of these findings tells us how children code location.

Several results do, however, bear on location coding, arguing for the hypothesis that the locations of array elements are coded individually with respect to an external framework of landmarks. Thus, perspective tasks are easy, even at 2 years, when children actually move around the array, because the targets can be located with respect to perceptually available landmarks. Similarly, perspective tasks are made easier by provision of a model of the room, showing landmarks as they would be located after movement to another position. The response children are asked to make is also important. Item questions (as opposed to position questions) can be answered well, at least by 5 years and possibly younger. This fact supports the idea that locations of targets and observers are coded with respect to the external framework and that perspective taking is possible when answers can be read from the representation. Model-rotation devices are easy because the internal relationships of the display are maintained, and children can succeed by locating one object correctly. Most likely, children code the relationship of the observer to the object directly in front, and move the response device until that object is in front of them. This ability to code observer–near-object relationships is also shown by Harris and Bassett's finding that children as young as 4 years locate that object first in a model-building task. Overall, the impression gained from these findings is that location coding with respect to external frameworks is established at ages considerably younger than 9 or 10 years.

V. Related Tasks

A. EUCLIDEAN SPACE

The three-mountains task is described in 1 of the 15 chapters of *The Child's Conception of Space.* Many other experiments assessing understanding of projective space are also presented (e.g., construction of a straight line, projection of shadows). But little work has been done, except by Laurendeau and Pinard (1970), to examine these other techniques or the relationship of success on them to success on the three-mountains task.

Of the five chapters dealing with Euclidean space, two chapters have received more attention: work on children's ability to reproduce a model oriented differently from the child's model, and work on children's understanding of horizontality and verticality. Within the context of an interest in perspective taking, two questions about these tasks are of central importance. First, do children succeed on them at about the same time as on the three-mountains task, as might be expected if projective and Euclidean space are closely related? Second, can children's problems with these tasks be linked to the hypothesis advanced in this article concerning what makes various versions of perspective taking harder or easier? That is, would one have problems with these tasks if the location of objects is coded individually with respect to an external framework?

1. *Reproducing Model Placements*

Piaget and Inhelder presented to children a model of a village, showing a stream, a road crossing, hills, trees, and houses. In one task, children were asked to place a doll on a second model, rotated 180° and separated from the first by a screen. At 3 or 4 years, placements were determined by closeness to a single salient object or background. From 4 to 7 years, children exhibited some ability to place the doll correctly; by 7 to 8 years, placements were determined by logical multiplication of left–right and before–behind relationships. Success occurred later on a more complex task, that of reproducing the whole model either diagrammatically or by using model materials. In this task, a system of reference was established by ages 7 to 10 years, with distance and proportion not fully accurate until after that.

Using model villages and the doll-placement task, Laurendeau and Pinard (1970) obtained similar results, with placements by younger children determined with reference to the self or a single point in the model. Laurendeau and Pinard did not find complete success on the most difficult placements until 10 years of age. Using more abstract materials and no topographic cues, Pufall and Shaw (1973) found that 10-year-olds still had difficulty in accurate placement. However, Pufall (1975) found better performance in 5-year-olds who used a farm scene; the children also did better when the child's model was rotated 90° rather than 180° from the experimenter's. Russell (1982) found that 5-year-olds improved somewhat on an allocentric placement task following training, but their performance was still quite poor.

These studies show a rough congruence between ages of success on perspective taking and allocentric placement tasks. But of course, the same could be said for perspective taking and conceptually unrelated cognitive achievements—for example, use of memory strategies. Laurendeau and Pinard (1970) and De Lisi *et al.* (1976) studied perspective taking and allocentric placement in children ages $4\frac{1}{2}$ to 12 and 6 to 11 years old in the respective studies, and found that success on the two tasks was related. However, with age varying as widely as it did, this association does not demonstrate that the two tasks are indexing acquisition of related systems of spatial representation, as Laurendeau and Pinard recognized.

Laurendeau and Pinard showed that a scalogram analysis of their five spatial tests indicated a consistent order of acquisition across subjects, of the substages of thought delineated for each of the tests separately. They argued that this finding indicated that a common line of development was tapped by all five tests, because inclusion of sequences from tests of causal thinking lowered the scalability of the data. However, the lowering was not large and it was not tested for statistical significance. General mental development seems adequate to explain the scalogram results.

The approach to spatial coding and the perspective-taking task taken in this article suggests the hypothesis that allocentric placement is difficult for the same reason that perspective taking with appearance questions is difficult: The child is asked to place objects in manifestly different positions with respect to the external framework of the room. This hypothesis would explain the substantially greater difficulty of allocentric placement in the model studies as compared to the performance levels found in studies of "large-scale space" (e.g., Herman, Roth, Miranda, & Getz, 1982). Herman *et al.* found that children as young as 5 years had little difficulty in reproducing a layout of eight unrelated objects after moving to the other side of the room. In this case, the physical relationship of the targets to the external framework remains invariant. Success with a rotated model however, requires the suppression of attention to external cues and a focus instead on the internal relationships among objects in the model. Such internal coding is a difficult task, as discussed further in the next subsection.

2. *Horizontality and Verticality*

Considerable work has been done on children's understanding of orientation to the gravitationally defined horizontal and vertical—for example, as in understanding of the fact that still water levels are horizontal (e.g., De Lisi, 1983; Liben, 1975; Thomas & Jamison, 1975). Much of this work has concerned the persistence of errors on these tasks into adulthood, especially among women (e.g., Liben & Golbeck, 1980). However, the majority of subjects are doing well by early adolescence. Thus, again, some rough congruence exists with perspective taking; although adults rarely make errors on the picture-choice task, they do have some difficulty with building models (Presson, 1982).

Horizontality-verticality and perspective-taking tasks have been given to the same groups of subjects by Larsen and Abravenel (1972). They found significantly earlier acquisition of horizontality-verticality than of perspective taking among 5- to 10-year-olds; they did not assess correlations among the tasks. De Lisi *et al.* (1976) showed a correlation between horizontality-verticality and success in allocentric placement among 6- to 11-year-olds. In a potentially more stringent test of the relatedness of projective and Euclidean concepts, Cox (1977c) found no transfer of successful training of 5-year-olds in perspective-taking to water-level task.

The difficulty of horizontality-verticality tasks seems closely related to the problem of selecting the correct framework within which to draw the stimulus. Children often choose the sides of the bottle rather than the gravitational horizontal as a referent for drawing water level or the sides of the hill rather than the gravitational vertical for drawing plumb lines. Their problems thus do not seem to involve use of external landmarks in the room, as do problems with perspective taking. This fact is not surprising, given that the stimuli are self-contained flat pictures rather than a group of objects with physical locations in the room.

B. MENTAL ROTATION

Piaget and Inhelder (1966/1971) reported the results of extensive investigations of children's ability to imagine static and moving objects, both already seen and anticipated. One of their main arguments was that "at about 7 to 8 years a capacity for imaginal anticipation makes its first appearance, enabling the subject to reconstitute kinetic or transformational processes, and even foresee other simple sequences" (p. 358). The lack of imagery in preoperational thought was linked to the general tendency of thought at that stage to focus on states rather than transformations. By contrast, operational thought was said to allow the coordination of successive states and the transformations that lead from one to the other.

The finding that children could imagine the outcome of rotation of an object on its own axis by the age of 7 or 8 years contrasts somewhat with the conclusion that perspective taking cannot be carried out until 9 or 10 years, but Piaget and Inhelder did not directly compare their results on mental rotation to results on perspective taking. However, Huttenlocher and Presson (1973) showed that for 8- and 10-year-olds, imagining the outcome of mental rotation of an array on its axis was in fact easier than imagining what an array would look like to a hypothetical observer using a model-selection task (appearance questions). These findings have been replicated by Finlay (1977) with 7- and 8- as well as 9- and 10-year-olds. P. L. Harris and Bassett (1976) also found rotation easier than perspective taking.

Array rotation is usually easier than perspective taking, in that it does not require the child to locate a hypothetical observer before transforming the array. Thus, solving these problems requires fewer mental steps (Huttenlocher & Presson, 1973), as long as the response allows the subject to focus on only one object (appearance questions) or on one object at a time (model building). Array rotation is difficult when answering item questions, however, because the subject must transform all the objects in the array to decide which one occupies the specified position. Such a task would not be hard if the locations of the objects were internally coded with respect to each other; the difficulty of array rotation with item questions in contrast to its ease with appearance questions is what suggests that such internal coding does not occur even in adults (Presson, 1982).

Thus, mental rotation seems to be either easier or harder than perspective taking, depending on whether the dependent variable used places a premium on internal coding for rotation problems (as item questions do) or on abstracting coding away from an external framework (as appearance questions do). For perspective taking, data suggest that as young as 5 years, children are able to perform effectively as long as they do not need to abstract away from an external framework, with item questions (Newcombe, 1989). Can mental rotation be observed at ages younger than the 7 or 8 years suggested by Piaget and Inhelder?

Considerable controversy concerns whether mental rotation is possible in children as young as 4 or 5 years. Much of the research concerns rotation of single objects. Marmor (1975, 1977) presented evidence that children as young as 4 or 5 years showed linear slopes of reaction time as a function of the amount of rotation required, suggesting that they did perform mental rotation. Other investigators have failed to find linear slopes for younger subjects (e.g., Dean & Harvey, 1979). In a 1987 review, Dubas concluded that although children as young as 4 or 5 year often do show linear slopes, many of them may be cognitively precocious. Error rates are high at these ages. Dubas also found that when concrete operations are tested, demonstrably preoperational children do not show reliable evidence of linear slopes. These children may be performing rotation tasks, when they can do so at all, by memorizing the appearance of the stimulus at various degrees of rotation.

The evidence on mental rotation of multiple-object arrays by young children is quite sparse. Using a multiple-location hiding task, Lasky, Romano, and Wenters (1980) found that children of 3, 4, and 5 years were at or below chance. Performance was better than chance at 7 years, but not really good until age 10.

In summary, current evidence suggests that array rotation is neither easier nor harder, across the board, than perspective taking. The difficulty of each depends on the exact coding requirements of the task. Very young children have great difficulty with internal coding or separated targets and with abstracting codings with respect to external landmarks away from these landmarks. But older children and adults continue to have marked difficulty with these same processes.

VI. Conclusion

Children's solutions to spatial problems pose an intriguing puzzle in development. For some time, difficulties with such tasks have been thought to index a pervasive characteristic of children's thought, called "egocentrism," but recent research has shown clearly that at least by 2 years of age, children are not egocentric in the sense of not knowing that other people see displays differently. The main argument of this article has been that perspective-taking tasks, and other spatial problems such as mental rotation, are difficult (or easy) for reasons that include the demands the particular problem makes on the usual form of representation of space. From at least 5 years of age, and perhaps earlier, this representation seems to be one in which small movable targets are encoded in relation to a framework of fixed landmarks, rather than in relation to each other. Such coding makes ecological sense, because movable items, almost by definition, make poor reference points for the location of other objects. Thus, spatial coding does not seem to change across middle childhood in the fashion discussed by Piaget. What remains for the future is to explore whether frameworks of landmarks are used soon after the beginning of free locomotion, and how location coding changes, if it does, in the first few years of life.

From the point of view of investigators primarily interested in perspective taking, the main conclusion of this chapter is that an intellectually respectable form of perspective taking can be demonstrated as early as 5 years. Many factors can add to the difficulty of the task for children in middle childhood, and some of these performance factors are of interest in their own right. But investigation of them should not proceed as if their existence precluded the existence of a perspective-taking competence.

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