Developmental Psychology
1989, Vol. 25, No. 6, 983–995

0012-1649/89/$00.75

Parts, Partonomies, and Taxonomies

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Partonomies, such as body parts, like taxonomies, such as the animal kingdom, are hierarchical organizations of knowledge based on an asymmetric, transitive relation, *part of* or *kind of*. This article reports exploratory work on children's partonomic knowledge, and the relation between partonomic knowledge and use of taxonomic organization. Because parts are elements of both appearance and function, shared parts may facilitate the transition from classification based on perception to classification based on function. Children were more likely to group taxonomically when instances shared parts than when instances did not share parts. For adults, parts rated "good" are functionally significant as well as perceptually salient, for example, the *seat* of a chair. Perceptually salient parts—those affecting shape or large ones—were detected faster by younger children than were less salient parts.

One way to reach an understanding of a complex idea is to subdivide it. Many concepts can quite naturally be subdivided in more than one way. To study *government*, for example, one can examine kinds of governments, such as democracies, dictatorships, and monarchies, or, alternatively, parts of governments, such as the executive, legislative, and judicial branches. Even a simple, *basic level* (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976) concept such as table or fish can be, on the one hand, readily decomposed to kinds, such as dining table and coffee table or perch and trout, or just as easily subdivided into parts, such as top and legs or fins and tail. In fact, when asked to list subdivisions of concepts such as these, about half of a group of 60 students consistently produced kinds, and the other half, just as consistently, produced parts. These two modes of decomposition reflect two general forms of organization of knowledge, *taxonomic*, that is, subdivision into kinds, and *partonomic*, that is, subdivision into parts (a similar distinction has been explored by Mandler, 1979; Markman, 1981; and Miller & Johnson-Laird, 1976). Both forms of organization have cultural universality (Berlin, 1978; Brown, 1976; Ellen, 1977), and both produce hierarchies based on transitive, asymmetric relations. A pippin is a kind of apple, and because an apple is a kind of fruit, a pippin is also a kind of fruit. A fruit, however, is not a kind of apple. Similarly, a piston is a part of an engine, and thus a part of a car, but not vice versa. Both forms of organization are appropriate to both concrete concepts, such as objects, and to abstract concepts, such as governments and organizations.

In taxonomic hierarchies, property inferences are usually permissible; if apples are spherical, then so are subcategories of apple. Property inferences are usually not appropriate in partonomies; the car may be a beauty, but its pistons probably are not. Division into parts may support another kind of inference important in human cognition—the inference from appearance to function (Tversky, 1986; Tversky & Hemenway, 1984). When examining an object, for instance, one can divide it into parts by perceptual salience and attempt to understand the role of each part separately. This strategy is based on knowledge about appearance and function of parts in common objects. Although it is certainly not necessarily the case that parts that are perceptually distinct also have distinct functions, this seems to be true of many common objects and organisms. The legs of a chair and the back of a chair are perceptually different, and have different functions, as do the peel and pulp of a banana and the fins and gills of a fish. Parts, then, seem to be simultaneously natural units of perception and natural units of function. A few parts suggest (or afford) their function by their very form—handles and seats, for example. This is evident from metaphoric uses of parts as well: An *arm*, of a chair or a phonograph, for instance, may be a part that resembles a human arm, that is, long and thin, or it may be a part that functions like a human arm, that is, for reaching or support.

Although research dedicated to understanding partonomic knowledge is relatively rare, psychologists, linguists, anthropologists, and others have devoted considerable research to understanding taxonomic organization and categorization in both adults and children. In taxonomies, basic-level categories, as opposed to more abstract or more specific categories, have a special status in many cognitive tasks. This is the level of *table* and *fish*, as opposed to *furniture* and *animals* or *dining table* and *perch*. That level is the most abstract level for which an

This research was supported by National Institute of Mental Health Grant MH34248 to Stanford University, by National Science Foundation–Information Science and Technology Grant 8403273 to Stanford University, by a grant from the Human Development Institute of the Hebrew University, and by the Batsheva de Rothschild Fund in Jerusalem.

I am grateful to Miriam Bassok, Roger Brown, Kathleen Hemenway, and Irene Miura for assistance in the conception and execution of the experiments and to Ellen Markman for helpful discussion. Thanks are due the staff and children of the Hebrew University Summer Day Camp, Bing Nursery School, Lucille M. Nixon and Escondido Village Elementary Schools, Palo Alto Community Child Care, and Sacred Heart School of Menlo Park for their enthusiastic cooperation and assistance.

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image can be formed, the highest level at which a composite shape can be recognized, the highest level for which behavior patterns are similar, the level most quickly verified or named, the level named earliest by children, and more (Murphy & Smith, 1982; Rosch, 1978; Rosch et al., 1976). When asked to produce attributes of categories at various levels of abstraction, subjects produce few at the superordinate level and many at the basic level (Rosch et al., 1976). Most attributes produced at the basic level are parts, and there is high agreement across subjects as to which parts are named (Tversky & Hemenway, 1984). Because parts are both elements of appearance and elements of function, they may underlie the informativeness of the basic level and account for the convergence of many cognitive operations at that level as well (Tversky, 1986; Tversky & Hemenway, 1984). On the one hand, parts, in the proper configuration, determine the shapes objects can take, and therefore account for the measures depending on appearance; on the other hand, behavior toward objects is directed toward different parts, accounting for measures reflecting function.[1] Both forms of organization, taxonomic and partonomic, are salient and available at the basic level; there are kinds of tables and shirts, and they have parts as well. In contrast, the superordinate level (furniture and clothing) can usually be subdivided into kinds but not into parts. Although the subordinate level, such as coffee table and dress shirt, can potentially be subclassified into kinds, such subclasses are not readily available or agreed upon. In contrast, parts of subordinates enjoy both availability and consensus; they are, in fact, generally the same parts as of the corresponding basic category, table and shirt.

Preschool children easily sort different objects or pictures of objects into basic-level categories (Rosch et al., 1976), for example, several instances of cars or tables. Categories at this level of abstraction have a strong perceptual basis; they tend to have similar shapes (Rosch et al., 1976) and, even more fundamentally, the same parts (Tversky & Hemenway, 1984). Preschool children do not readily sort different basic-level objects or pictures of objects into superordinate categories (vehicles or furniture); instead, they prefer other forms of organization, for example, thematic or perceptual (Bruner, Olver, & Greenfield, 1966; Markman & Callanan, 1984; Melkman, Tversky, & Baratz, 1981; Smiley & Brown, 1979; Tversky, 1985). Although basic-level categories share both perceptual features and function, superordinate categories do not share perceptual features, but do share more abstract properties, most commonly function. Vehicles, such as boats, planes, and trains, and clothing, such as jackets, shoes, and pants, do not have parts or perceptual features in common; they share the ability to transport people or things or to cover the human body. Many functional properties are not perceivable in the way that perceptual properties are. We know by looking at an object that it is round or red or rough, but we cannot know simply by looking at it if it is edible or makes music or is used in construction. Knowledge of function depends on rather specific prior experience. For example, grouping an orange with the sun rather than a banana, because both are round, children are using the sorts of perceptual criteria that are successful in basic-level categorization rather than the more abstract functional criteria underlying superordinate categories and favored by older children and adults (Melkman et al., 1981).

The studies to be reported are exploratory forays into children's partonomic knowledge and the role of partonomic knowledge in taxonomic organization. One of the difficulties children may have with superordinate categories is comprehending that an object can belong to more than one category at once, for instance, that the round, red thing the child eats for a snack is both an apple and a fruit, or that "Daddy" is not only a father but also a man (Markman & Wachtel, 1988). Another difficulty inherent in superordinate categories, however, is that they are based in function alone and not in perception. This suggests that it should be easier for children to form superordinate categories when the items to be grouped share parts. As noted, parts play a dual role in categorization; they are both elements of perception and elements of function. Thus, grouping can be done on a perceptual basis, by shared parts, where parts are perceptually distinctive. Then, if the function of the shared parts is known for any one of the objects, it can be inferred for the others. For example, a broom, a rake, and a shovel all have long handles, an easily perceived part conducive to grouping together. If, then, a child knows that the handle on any one of the objects is used for holding and moving the object, the child may readily make the inference of this function to the other objects. Additionally, grouping several objects together by shared parts may make their shared function more apparent. Because a blouse, a jacket, and a sweater all have arms, a neck hole, and a chest piece, they may be grouped together and their common function, of covering the upper body, noticed. If the presence of shared parts facilitates superordinate categorization in children, it may also be because parts form a bridge from categorization based on perception to categorization based on function.

The first experiment, then, explores the role of parts in children's taxonomic grouping. The remaining experiments examine perceptual factors in the detection of parts. All of the experiments use natural objects well-known to young children as stimuli.

Experiment 1: Grouping by Shared Parts

In this experiment, children were asked to group 15 pictures of common objects in a standard taxonomic sorting task. There were two sets of objects, each consisting of 3 common objects from 5 superordinate categories. In one set, the items from each category were selected so that they shared parts. Because parts underlie the shapes objects may project, an inevitable consequence of sharing parts is increased similarity of shape. In the other set, items were selected to minimize sharing of parts, but, wherever possible, to be on the average more frequent and more typical. Children group familiar items at an earlier age than unfamiliar ones (Horton, 1982), and both children and adults group more typical category instances earlier than less typical instances (Mervis, 1980; Mervis & Pani, 1980; Mervis & Rosch, 1981). Five-year-old children were selected for the study be-

[1] All of the cognitive operations converging on the basic level that concern appearance happen to concern only shape and not other aspects of appearance, such as color or texture. In fact, those nonshape aspects of appearance seem to be more important in subordinate categorization than in basic-level categorization (Tversky & Hemenway, 1984).

Table 1
Objects in Categories for Each Stimulus Set

Category	Shared parts	High typicality
Animal	Bear, cow, deer	Cat, fish, snake
Clothing	Blouse, jacket, sweater	Dress, shirt, socks
Furniture	Bureau, desk, bookcase	Bed, chair, dresser
Tools	Broom, rake, shovel	Paintbrush, ruler, saw
Vehicles	Bus, train, trolley	Airplane, motorcycle, truck

cause that age is transitional to superordinate categorization (see, e.g., Markman & Callanan, 1984).

Method

Subjects. The subjects in this study were upper-middle-class preschoolers attending Stanford University nursery school. A total of 32 children participated, half boys and half girls. The mean age of the boys was 5 years, 0 months (range = 4 years, 7 months to 5 years, 4 months); the mean age of the girls was 4 years, 11 months (range = 4 years, 5 months to 5 years, 4 months).

Stimuli. Two sets of 15 pictures of common objects were prepared. Each black ink drawing was centered on a white card, 6.5 × 7.6 cm. Three objects from each of 5 familiar taxonomic categories were selected. The 15 objects in each set are listed in Table 1. For one set of pictures, the objects from the same taxonomic category shared parts. For example, the tools (rake, broom, and shovel) all had a long handle, the clothing articles (blouse, jacket, sweater) all had sleeves and a body, and the animals had four legs and faces. The different parts set of objects came from the same five taxonomic categories as the first set, but were selected so that, on the average for each category, word frequency was higher for the different parts set. The American Heritage norms (Carroll, Davies, & Richman, 1971) were used because they are based on children's readers. For the three categories in which typicality norms were available for all instances (clothing, furniture, and vehicles), typicality ratings were higher on average for the different parts set (norms from Rosch, 1975). For both the shared parts and the different parts sets of stimuli, some of the taxonomic groups seem to form subgroups, although attempts were made to minimize this. After the fact, it is possible to construct a way to relate almost any three category members. Thematic subgroups such as those preferred by younger children tended to be more prevalent in the high-typicality set, where paintbrush, ruler, and saw are all used by carpenters, and bed, chair, and dresser all are found in bedrooms.

Procedure. The experimenter, a male graduate student, sat opposite the child at a small table. He told the child to look carefully at the pictures to be placed on the table. The pictures were shuffled and then placed one at a time on the table in a random pattern. After all the pictures were displayed, the experimenter asked the child to put together the objects that "belonged together, that were the same *kind* of thing." The experimenter also told the child to make as many groups with as many objects in each as was needed and to try to find a place for all the objects. When the child finished grouping the objects, the experimenter asked why the objects in each group belonged together or were the same kind of thing.

The experimenter repeated the above instructions and procedures with the second set of pictures. Half of the subjects grouped the shared parts stimulus set first and half the different parts set.

Results

Of interest is the number of taxonomic groupings formed by children for each stimulus condition as well as the extent of taxonomic justifications given for the groupings. A justification was counted as taxonomic if it referred to a name for the superordinate category or to a function shared by category members. Four related dependent measures of subject performance were analyzed: the number of taxonomic groups consisting of two or three items; the same, with taxonomic justifications; the number of taxonomic groups of three items; and the same, with taxonomic justifications. The means are reported in Table 2.

Each of these four measures of grouping was subjected to an analysis of variance (ANOVA) with stimulus set (shared parts vs. high typicality), stimulus set order, and sex of child as factors. For all four measures, grouping was significantly greater for the shared parts stimulus set than for the different parts stimulus set: two or more items, $F(1, 28) = 9.47$, $p < .005$; two or more items plus taxonomic justification, $F(1, 28) = 14.39$, $p < .0007$; three items, $F(1, 28) = 13.43$, $p < .001$; and three items plus justification, $F(1, 28) = 16.61$, $p < .0003$. For each of the 5 categories, there were more two- or three-item groups in the shared parts condition than in the different parts condition. Moreover, 17 of the 32 children had more groups in the shared parts condition than in the different parts condition; another 12, 10 of whom were at ceiling, had equal numbers of groups in both conditions; and 3 children had more groups in the different parts condition. Across both conditions, there was a consistent order of categories by number of children forming groups of 2 or 3. From most to least, that order was animal, clothing, tool, vehicle, and furniture. There were no main effects attributable either to stimulus set order or to sex of child. The only other significant effect was a three-way interaction between stimulus set, stimulus order, and sex for the groups of two or more items with justifications, where girls' scores were higher when the shared parts set was first. There were a total of 23 nontaxonomic groups formed in the different parts condition and 11 in the shared parts condition. Twelve children in the different parts condition and 6 children in the shared parts con-

Table 2
Average Number of Taxonomic Groups Formed for Each Stimulus Set (Maximum = 5)

	Two or more items: No. of		Three items: No. of	
Stimulus set	Groups	Justified groups	Groups	Justified groups
Shared parts	4.63	4.25	3.72	3.59
Different parts	3.91	3.34	2.75	2.56

dition produced at least one nontaxonomic group. These groups were given thematic explanations for the most part (e.g., the brush with the chair because "the brush paints the chair," or the rake with the bus because "the rake rakes the leaves off the bus").

The average rank order of category formed was also subjected to an ANOVA with category, sex, and stimulus set as factors. The effect of category was significant, $F(4, 112) = 4.18$, $p < .003$; overall, categories were formed in the following order: clothing, vehicles, tools, animals, and furniture. Category order, however, interacted with sex, $F(4, 112) = 2.92$, $p < .02$. For boys, the order was vehicles, clothing, animals, tools, and furniture; for girls, the order was clothing, tools, vehicles, furniture, and animals. Category order also interacted with stimulus set, $F(4, 112) = 3.19$, $p < .02$. In the shared parts set, the order of forming categories was vehicles, clothing, tools, animals, and furniture; in the different parts set, the order was clothing, furniture, animals, tools, and vehicles. The triple interaction was not significant.

Discussion

Young children form superordinate taxonomic groups more readily when category members share parts than when category members do not. Because objects that share parts naturally have more similar shapes than objects that do not, it is not easy to disentangle effects of shape from effects of parts. Nevertheless, using artificial stimuli, Hock, Tromley, and Polmann (1988) found that classification learning was better when category members shared parts rather than overall configuration. Parts serve a dual role in basic-level categories. On the one hand, in the appropriate configuration, they determine the shapes objects have. On the other hand, behaviors are typically directed toward the separate parts of objects, not to objects as wholes, so that parts also underlie function. We remove the peel of a banana and eat the pulp; we sit on the seat of a chair and lean against the back; we grasp the handle of a hammer and pound the nail with the hammer's head.[2]

Whereas basic level categories have both a perceptual and a functional basis, superordinate categories are generally only functionally based. To form superordinate categories, the child needs to switch from a perceptual to a functional basis for categorization. Shared parts may facilitate that transition. First, objects sharing parts will necessarily be more perceptually similar than objects not sharing parts. Thus, by relying on parts, children may continue to use a perceptual criterion for grouping, and may thereby succeed in forming adult superordinate categories. Second, attention to parts may also draw attention to the functions served by the parts, and thereby to a functional basis for categorization. This is supported by the finding of more taxonomic justifications for grouping in the shared parts set. This line of reasoning is speculative. What has been shown is that young children are more likely to group instances into superordinate categories and more likely to give taxonomic justifications for doing so when the instances share parts than when they do not share parts.

Experiment 2: Perceptual Determinants of Detection of Parts

The finding that children form taxonomic groupings more readily when objects share parts than when they do not suggests that young children attend to parts. Which parts do they attend to? In an investigation of adult conceptions of parts of natural objects, Tversky and Hemenway (1984) presented subjects with parts of objects (generated by other subjects) to be rated for "goodness." Parts varied widely on rated goodness, yet there was considerable agreement across subjects as to which parts were good and which were not. Parts rated as good tended to be both perceptually salient and functionally significant, for instance, the legs of pants, the seat of a chair, and the blade of a saw. Goodness of part, then, is analogous to goodness of exemplar, or typicality. Just as some category members are better exemplars of categories than others, some parts of objects are better parts than others. Apples are more typical fruit than watermelons, and chairs are more typical furniture than rugs (Mervis & Rosch, 1981; Rosch, 1978; Rosch & Mervis, 1975).

There have been several attempts to analyze the perceptual variables according to which people parse forms into parts. Kosslyn, Heldmeyer, and Glass (1980) asked children and adults to indicate the separate parts of nonsense forms. Abrupt changes in contour had a large effect on parsing at all ages, and texture and color changes had a smaller effect that increased with age. Hoffman and Richards (1984), in fact, have proposed a model in which local minima in contours are used to parse contours into parts. Biederman (1985) has recently presented evidence that perceptual recognition of objects is dependent on decomposing objects into sets of component parts drawn from a modest (approximately 36) number of components distinguished by inflection points. Bower and Glass (1976) and Palmer (1977) have demonstrated that Gestalt factors determine significance of parts; parts with greater integrity and parts that bear a greater resemblance to whole objects are more likely to be perceived and remembered. Palmer, Rosch, and Chase (1981) found that for common objects and organisms, subjects agree that certain viewpoints are better or more canonical than others. Inspection of the canonical views suggests that they are the ones that reveal the more important parts of the objects and in contour. Consistent with the idea that outside contours are especially informative and important, Rock, Halper, and Clayton (1972) found that (adult) subjects remembered outside contours of nonsense forms better than inside contours.

Children are seemingly able to use shape or outside contour as a basis of classification at an early age. Basic level categories share common shapes, and such categories are attained by quite young children (Rosch et al., 1976). Are children also more sensitive to parts that affect the canonical contour than those that

[2] Superordinate categories have more global functions, such as "for eating," "for fixing," or "for transporting"; however, these are instantiated differently for different objects. These instantiations seem to be part-specific; the parts that make music are different for a piano than for a flute, and the parts that are for fixing are different for a saw than for a hammer. Very few basic objects come to mind that function as a whole; one that does is ball, and ball does not have psychologically compelling parts.

Table 3
Objects and Corresponding Internal and External Missing Parts

Object	Missing part: Internal	Missing part: External
Boat	Seat	Oar
Car	Headlight	Wheel
Desk	Drawer	Leg
Fish	Fin	Tail
Horse	Mane	Tail
House	Door	Chimney
Lamp	Bulb	Cord
Shirt	Pocket	Collar
Sink	Drain	Faucet
Telephone	Dial holes	Cord

do not? Some important parts of objects are visible, yet do not affect the canonical shape of the object, for instance, the drain of a sink or the door of a house. Because of their relative lack of perceptual salience, these parts may be more difficult to detect than parts that affect the portrayed contour of the object. This experiment investigated reaction time to detect a part present in one picture of an object but missing in a second picture of the same object. First graders were selected for this study so that the error rate would be low enough to measure reaction time reliably. It was predicted that missing external parts would be detected more quickly than missing internal parts. *External part* refers to a part that affects the canonical contour of the object, whereas *internal part* refers to a part that is still visible, (i.e., on the outside of the object) but that does not affect the canonical contour of the object. For half of the subjects, the task was a *perception* task, that is, picture pairs were presented simultaneously, and for half the subjects, the detection task was a *memory* task, that is, the picture with the missing part was presented after the complete picture.

Method

Subjects. A total of 64 middle- to upper-middle-class children participated in the study, half boys and half girls. The mean age of the boys was 7 years, 1 month (range = 6 years, 8 months to 7 years, 9 months) and the mean age of the girls was 7 years, 1 month (range = 6 years, 7 months to 7 years, 9 months).

Stimuli. The stimulus set consisted of 10 triads of line drawings of common objects. The triad of pictures of each object included a standard, or complete, picture; an internal picture, or picture with an internal part of the object missing; and an external picture, or picture with an external part of the object missing. Care was taken that size and importance of internal and external missing parts were about the same for any triad. The objects and missing parts are listed in Table 3, and some examples appear in Figure 1.

Design and procedure. A male graduate student tested each child separately. The child was told that two pictures of the same object would be shown, and that an important part would be missing from one of the pictures. The child's task was to detect the missing part. In the perception condition, the child was told that the pictures would be shown side-by-side with the incomplete picture on the left. In the memory condition, the child was told that the standard picture would be shown first (for 30 s), and then replaced immediately by the incomplete picture. The child was to identify the missing part as quickly as possible, and announce it to the experimenter while pressing a key attached to a colorful box. Pressing the key stopped the clock that the experimenter started simultaneous with putting down the incomplete picture.

After two practice trials, the child saw the stimulus set in one of four random orders. Half the stimulus items had internal missing parts and half had external missing parts. No more than three items with either internal or external missing parts were presented consecutively. Same-sex children were paired so that if one child saw a particular stimulus with a missing internal part, the partner saw the same stimulus with a missing external part.

Results

The average reaction time to detect an external missing part was 3,183 ms, whereas the time to detect an internal missing part was 5,408 ms, a substantial difference, $F(1, 60) = 33.97$, $p < .00001$. There was no effect of or interaction with presentation condition, simultaneous or successive. Boys were 578 ms faster than girls, $F(60, 512) = 1.50$, $p < .01$. Although there were, on the average, fewer than 3 errors per child, analysis of errors corroborates the reaction time data. There were a total of 35 errors when the missing part was internal, as opposed to 13 errors when the missing part was external. There were more errors in the successive condition (45) than in the simultaneous condition (3), and errors tended to be slower than correct responses, especially in the successive condition. Consistent with data from the next two experiments, most errors at this age were intrusions of plausible parts rather than thematic completions.

Discussion

In familiar objects, children detected a missing part affecting the portrayed contour of the object faster, by more than 2,200 ms, and more accurately than an internal missing part. Children, like adults, are sensitive to parts, particularly to parts that are highly salient—in this case, those affecting contours or canonical shapes of objects. Previous work using nonsense forms (e.g., Bower & Glass, 1976; Kosslyn et al., 1980) showed that other factors, such as color, texture, and completeness, may affect the perceptual salience of parts as well. Both size and location of part enjoy ecological validity as well as perceptual salience: In many familiar objects, parts that are large or that affect canonical shape are also important, such as the arms or legs of a person or chair. In the world, then, perceptual salience seems to be a good cue to functional significance. Thus, attending to salient parts may be an effective way of learning about function. The next set of studies examines children's knowledge of parts more directly.

Experiment 3: What's Missing? Part 1

One way to assess children's partonomic knowledge is to present objects with a missing part and to ask which part is missing. Another way is to ask children to generate parts of objects. Each of these tasks has shortcomings, but the information obtained is complementary. The next two experiments use the first technique, and the last experiment, the second technique.

For this experiment, a set of simple line drawings of common objects (similar to those in Figure 1 and in all the present experiments) was devised. Each drawing portrayed a single object with no context. In each object, a small but functionally significant part was omitted (it is nearly impossible to draw a coherent, recognizable object with a large part missing). Children from 4 to 11 years of age were told that something was missing from each object, and were asked to tell the experimenter what it was. Two questions were of interest: First, would older children correctly detect the missing parts, but younger children not? Second, if the child failed to find the missing part, how would the child answer?

Method

Subjects. There were four groups of children drawn from lower-middle- to middle-class nursery schools and day camps in Israel. The youngest group consisted of 17 girls and 10 boys with an average age of 4 years, 4 months. The second group consisted of 20 girls and 20 boys with an average age of 6 years, 0 months; the third group had 21 girls and 18 boys with an average age of 8 years, 1 month; and the oldest group included 20 girls and 20 boys with an average age of 11 years, 0 months.

Stimuli. The stimuli were 14 black ink line drawings, similar to those in the previous study, of familiar objects on cards 13 × 16 cm. Each card portrayed a single object with a small but important part missing. A list of the objects and their missing parts is presented in Table 4.

Procedure. Children were run individually in a quiet corner. The female experimenter told each child, "Now I will show you pictures of all sorts of things. Something important is missing from each of the things. Look carefully at each picture, and tell me the important part that is missing from the thing in the picture." The experimenter emphasized that something was missing from the object, and not from the drawing, although the object was not named.

The experimenter displayed the pictures one at a time. The order of pictures was randomized; half the subjects in each group viewed the pictures in one order, and the rest viewed the pictures in the reverse order.

Results

The children's responses were divided into four categories: correct responses; errors of omission (i.e., failures to respond); and errors of commission of two types, either thematic comple-

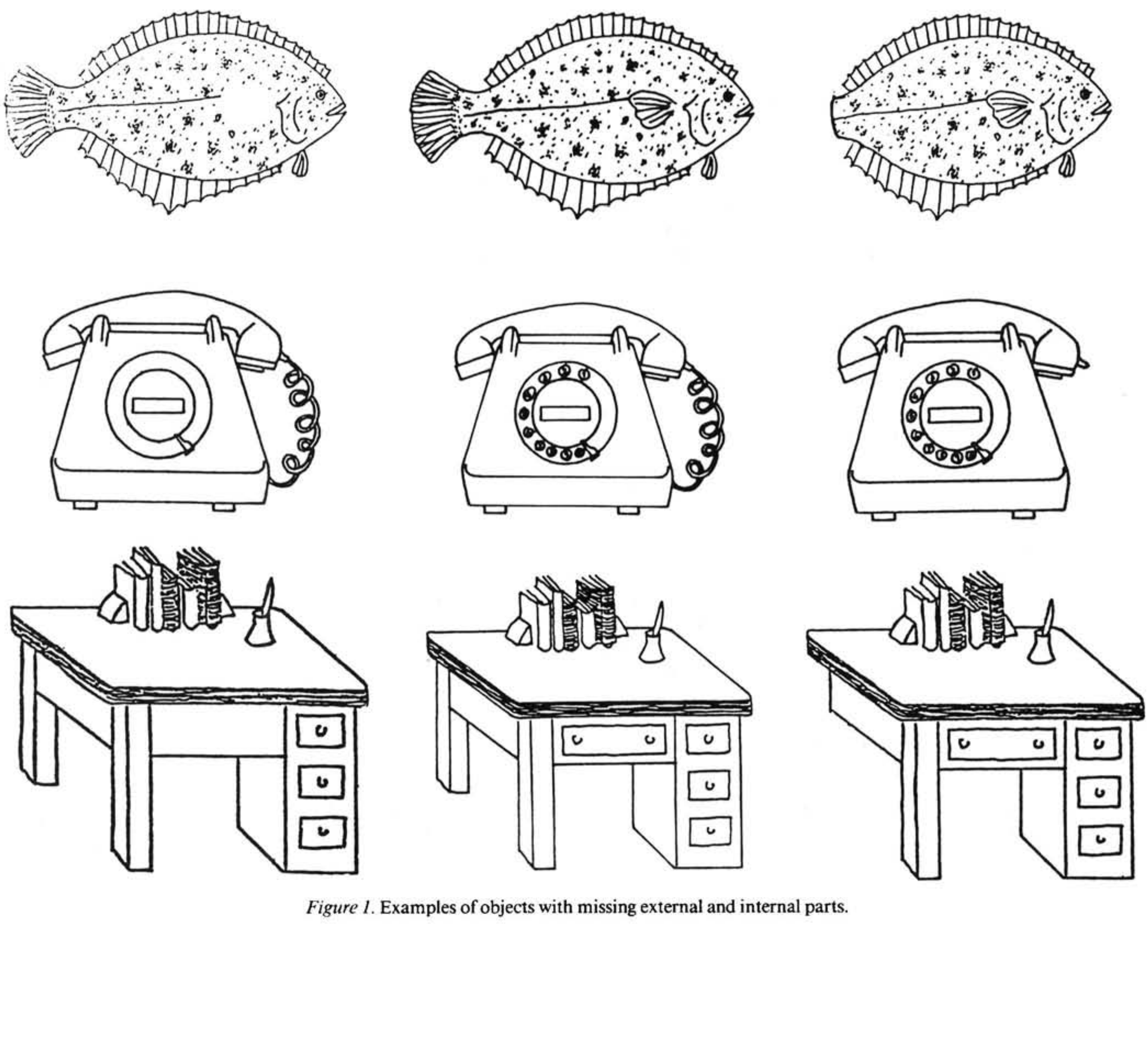

Figure 1. Examples of objects with missing external and internal parts.

Table 4
Depicted Objects, Missing Features, and Common Thematic Completions

Objects	Missing feature	Common completion errors
Pencil	Pencil point	Paper, hand, child
Shoe	Shoe lace	Leg, sock, child
Woman's bathing suit	One shoulder strap	Body, lady, arm, head, sea
Desk lamp	Electric cord	Man, table, wall, book, light
Face	Mouth	Body, legs, clothes, shoulder
House	Front door	Children, trees, fence, garden, path
Ladder	One rung	Man, wall, bucket, picture, telephone pole
Hand	One fingernail	Arm, body, boy, lady, glove
Car	One headlight	Man, driver, street
Watch	Minute hand	Man, hand (body part)
Rabbit	Tail	Field, carrot, cage, baby
Belt	Belt hole	Clothes, pants, man, watch, hand (body part)
Scissors	Screw (hold scissors together)	Man, paper, string, fabric, hand, finger
Screw	Slit (for screwdriver)	Screwdriver, man, board

Note. Objects are ordered according to increasing errors.

tion or other. Responses were scored correct if the subject clearly named the missing part or pointed to the location of it and either described it or stated its function. Thematic completion errors were defined as intrusions from a typical setting in which the object occurs rather than parts of the object itself, for example, *paper* for *scissors* (rather than the missing screw). While the parts are highly associated with the object, they are not inherent in the objects per se, nor, of course, did they appear in the drawing. Two judges agreed on what responses counted as completion errors, and a list of the common ones is provided in Table 4. Responses in the category "other commission errors" were typically those calling attention to stylistic aspects of the drawing (e.g., a line closing the hand or symmetry in the scissors) rather than referring to missing elements. Two of the stimuli were sometimes misinterpreted, from the experimenter's point of view: The belt without holes was taken for a watch strap and the rabbit without a tail for a kangaroo; however, in both of these cases, changing the object did not alter the missing feature. The percentages of each type of response to each picture averaged over all subjects are given in Table 5.

Age and patterns of errors. The sharp increase with age in correct responses is depicted in Figure 2. Age × Sex ANOVAS were computed for each of the four response categories. Age had a highly significant effect on all four categories: increasing correct response, $F(3, 138) = 90.61, p < .001$; decreasing completion errors, $F(3, 138) = 23.70, p < .001$; decreasing other errors, $F(3, 138) = 5.38, p < .002$; and decreasing failures to respond, $F(3, 138) = 16.80, p < .001$.

Increasing correct responses and decreasing thematic completions bore the strongest relation with age of all the response measures. Both these relations significantly deviated from linearity, though not from monotonicity, $F(2, 142) = 4.90, p < .01$, for correct responses, and $F(2, 142) = 2.94, p < .056$, for

Table 5
Percentages of Types of Responses Over Subjects

Objects	Correct	Thematic completions	Other errors	No response or "nothing missing"
Pencil	93.2	2.7	1.4	2.7
Shoe	85.6	9.6	2.7	2.1
Bathing suit	79.5	14.4	1.4	4.8
Desk lamp	74.0	8.2	6.8	11.0
Face	71.9	22.6	3.4	2.1
House	63.7	28.1	4.1	4.1
Ladder	63.0	19.9	9.6	7.5
Hand	58.2	28.8	10.3	2.7
Car	58.2	26.0	13.0	2.7
Watch	54.1	39.0	2.7	4.1
Rabbit	53.4	12.3	19.2	15.1
Belt	36.3	39.0	15.1	9.6
Scissors	29.5	34.2	10.3	26.0
Screw	25.3	40.4	9.9	14.4

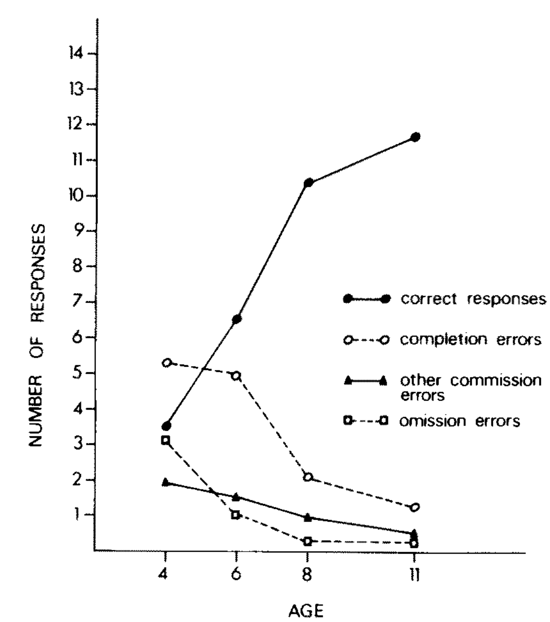

Figure 2. Age and error type in Experiment 3.

Table 6
Percentage of Thematic Completions That Are Physically Larger Than the Correct Missing Feature by Age and Sex

Age	Boys	Girls	*M*
4	92	94	93
6	86	93	90
8	78	93	87
11	78	84	81
M	84	91	88

thematic completions. Planned comparisons revealed that the greatest increase in correct responding and the greatest decrease in thematic completions occurred between the ages of 6 and 8.

At every age, the number of completion errors significantly outnumbered the number of errors of commission. This effect was particularly strong for the 4- and 6-year-olds, where the differences were 3.44, matched $t(26) = 4.41, p < .001$, and 3.43, matched $t(39) = 5.12, p < .001$, respectively. At age 8, the difference between completion errors and other errors dropped to 1.10, matched $t(38) = 2.34, p < .05$, and at 11, the difference was .68, matched $t(39) = 2.39, p < .05$.

Errors and size. Seven adult judges were asked to rank order the missing parts by (actual, not depicted) size. The averages of these ranks correlated significantly with the overall percentage correct on the pictures ($r = .6, p < .05$). Thus, larger missing parts were more frequently detected than smaller ones.

When children failed to detect the correct missing part, the most frequent error was to substitute a part of a scene in which the object would appear. At every age, the overwhelming majority of these thematic completions were parts that were physically larger than the part that was missing, for instance, reporting that the driver was missing from the car rather than the headlight. The percentages of completions that were larger than the correct missing part are presented in Table 6, broken down by age and sex.

Sex and patterns of errors and correct responses. Across all ages, boys performed better than girls, though this effect was smaller than the effect of age. Boys made an average of 9.35 correct responses, which is significantly greater than the mean for girls of 7.68, $F(1, 138) = 12.41, p < .001$. There was no interaction between sex and age on correct responses, and the effect of sex was significant even when age was a covariate, $F(1, 117) = 7.50, p < .01$. Boys made significantly fewer thematic completions than girls, 2.66 versus 3.77, $F(1, 138) = 5.40, p < .02$; however, the effect of sex on thematic completions was eliminated when age was a covariate. Boys committed slightly more other errors than girls, 1.37 versus 1.05, but this effect was not significant. Finally, girls omitted responses significantly more frequently than boys, 1.50 versus .62, $F(1, 38) = 7.03, p < .01$, and this effect remained in the analysis of covariance, $F(1, 117) = 5.81, p < .05$. In summary, boys produced more correct responses and fewer omissions than girls.

Discussion

Preschool children frequently fail to detect the absence of a small but functional part of a common familiar object. With age, performance increases considerably. Larger missing parts are more likely to be detected than smaller ones. When children failed to detect a missing part, they frequently substituted a large part of the typical context of the object. Because there was some ambiguity in the instructions as to whether the part was missing from the drawing or missing from the object, the study was replicated with instructions emphasizing that an important part was missing from the object.

Experiment 4: What's Missing? Part 2

This experiment is essentially a replication of Experiment 3, with small changes in stimuli, procedure, and population. Problematic stimuli were replaced, only two ages were used (4 and 7), and the instructions were revised so that the object was named by the experimenter. This was done to eliminate any ambiguity as to whether the picture itself or the object depicted was the reference.

Method

Subjects. Twenty 4-year-olds (mean age = 4 years, 3 months, ranging from 4 years, 0 months to 4 years, 7 months) and twenty 7-year-olds (mean age = 7 years, 0 months, ranging from 6 years, 7 months to 7 years, 7 months), half boys and half girls, from middle- to upper-middle-class backgrounds, participated in the study. Children were drawn from local preschools or day-care centers.

Stimuli. Stimuli were 14 black ink drawings of common objects, each missing an important part. The 14 objects and corresponding missing parts were belt (holes), car (headlight), face (mouth), hand (fingernail), horse (tail), house (door), ladder (step), lamp (cord), pencil (tip), scissors (screw), screw (groove on top), shoe (shoelace), sink (faucet), and watch (hands).

Procedure. The experimenter, a male graduate student, tested each child individually. The set of pictures was shuffled before they were presented to the child. The child was told to look carefully at each pictured object and was asked, "What important part is missing from the (name of object)?" If the child responded with "don't know" or did not respond, the experimenter placed the picture at the bottom of the stack and presented it later a second time. If the subject named a part present in the picture, the experimenter pointed to where the part was and asked the subject to look again for an important missing part. When the subject responded ambiguously, the experimenter asked the subject to say more or to point to where the missing part would be in the picture.

Results

Each response was assigned to one of three categories: correct, thematic completion errors, or other errors (omissions and other completion errors were grouped here because there were no interesting differences between them here or in the previous study). Responses were scored as in the previous study.

Separate ANOVAS were performed on total errors and thematic completion errors. The only significant effect was age: $F(1, 36) = 60.44, p < .001$, for total errors; and $F(1, 36) = 32.15, p < .001$, for thematic completion errors. Although boys in general outperformed girls, the effect was not significant in this study.

Figure 3 displays the mean number of total errors and thematic completion errors by age. The pattern of responding is

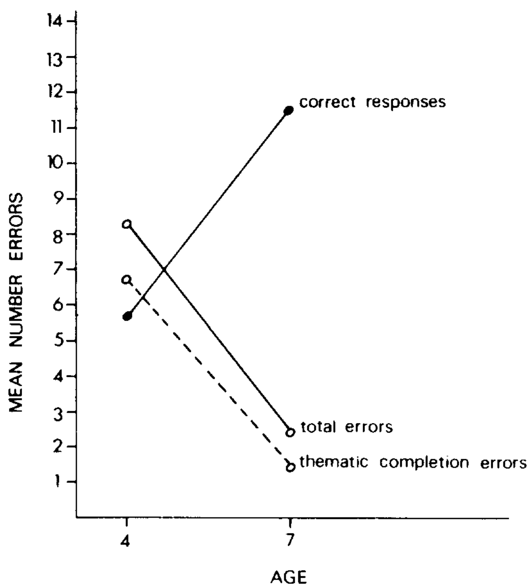

Figure 3. Age and error type in Experiment 4.

quite similar to that of the first experiment, although the absolute level of correct responding is higher in this study.

Tables 7 and 8 present Item × Age analyses for the younger age group for total errors and thematic completions. Except for the decrease in errors, the pattern is the same for the older children. It is readily apparent that some children consistently made more errors, that some stimuli consistently drew more errors, and that the children who made more errors made them on the same (more difficult) stimuli.

The increased level of performance in this experiment could be due to the decreased ambiguity of the task or to the greater socioeconomic status of the children sampled, or both. In both experiments, however, preschool children failed to detect missing parts, especially smaller ones, in more than half the objects, and early school-age children were already performing satisfactorily. When the younger children in both experiments failed to provide the correct missing part, they provided a larger part from the typical setting instead, in almost half the cases.

Experiment 5: Production of Parts

In two separate studies, children were asked to identify what part was missing from a common object. Young children frequently failed to produce the correct missing part, especially when the missing part was perceptually small. Moreover, they frequently produced a large element of the scene in which the object typically appears instead of the correct missing part. This suggests that young children's knowledge about object parts relies at least in part on perceptual salience. The substitution of unseen scene elements for actual missing parts is puzzling. It is possible that when thinking about parts, young children have difficulty separating the parts of an object from the parts of its usual context. Thematic relations are certainly very salient for young children (e.g., Markman & Hutchinson, 1984), and thematic associations (so-called *syntagmatic associations*) are readily available (e.g., Petrey, 1977). Although steps were taken to prevent this, another possibility is that children offered thematic associations when they could not find the actual missing part just to be able to say something to the experimenter. In the next task, children were simply asked to generate parts of common objects, cued either by the object's name or by a picture showing the object in a setting. Because children should have no difficulty producing at least some parts for each of the objects, there is no incentive to produce thematic associations. It is possible, however, that children will produce them even in this task. The pictorial cues should yield more parts

Table 7
Total Errors: Item by Age Analysis

Sex	Age	Car	Pencil	Shoe	Face	Horse	Lamp	Watch	House	Hand	Sink	Belt	Ladder	Scissors	Screw	Total
F	4:4								+		+					2
F	4:6				+						+		+	+	+	5
M	4:7					+				+		+	+		+	5
F	4:1								+		+	+	+	+	+	6
M	4:7				+					+		+	+	+	+	6
F	4:0			+					+			+	+	+	+	6
F	4:2	+					+	+		+				+	+	6
M	4:0					+			+	+	+	+		+	+	7
F	4:4						+		+		+	+	+	+	+	7
M	4:4					+	+	+	+		+			+	+	7
M	4:0					+	+			+	+	+	+	+	+	8
F	4:7	+			+			+		+	+	+	+	+	+	9
M	4:1		+		+	+	+			+	+	+	+	+	+	10
M	4:6		+	+	+			+		+	+	+	+	+	+	10
F	4:0		+	+		+	+		+	+	+	+	+	+	+	11
F	4:5		+	+	+			+	+	+	+	+	+	+	+	11
M	4:0	+		+	+	+	+	+			+	+	+	+	+	11
M	4:4	+	+		+		+	+	+	+	+	+	+	+	+	12
M	4:1		+	+	+	+		+	+	+	+	+	+	+	+	12
F	4:0	+	+	+		+	+	+	+	+	+	+	+	+	+	13
Total		5	7	7	9	9	9	9	11	13	16	16	16	18	19	

Table 8
Thematic Completion Errors: Item by Age Analysis

Sex	Age	Car	Lamp	Pencil	Shoe	Horse	Watch	Face	Belt	Ladder	House	Sink	Hand	Scissors	Screw	Total
F	4:4										+					1
F	4:4										+	+				2
F	4:2	+											+			2
M	4:4					+					+	+				3
M	4:7					+			+				+			3
F	4:0				+					+	+					3
F	4:1										+	+		+	+	4
F	4:6							+				+		+	+	4
M	4:0					+					+	+	+			4
M	4:7							+	+	+			+	+	+	6
M	4:1		+	+				+				+	+	+	+	7
M	4:0		+			+			+	+		+	+	+	+	8
F	4:7	+					+	+	+	+		+	+	+	+	9
M	4:6			+	+		+	+	+	+			+	+	+	9
F	4:0		+	+	+				+	+	+	+	+	+	+	10
F	4:5			+	+		+	+	+	+	+		+	+	+	10
M	4:1			+	+	+	+	+		+	+	+	+	+	+	11
M	4:0	+	+		+	+	+	+	+	+		+		+	+	11
M	4:4	+	+	+			+	+	+	+	+	+	+	+	+	12
M	4:0	+	+	+	+	+	+		+	+	+	+	+	+	+	13
Total		5	6	7	7	7	7	9	10	11	11	13	13	13	13	

than the verbal cues because the pictures suggest them explicitly.

Method

Subjects. A total of 48 children participated, ranging in age from 4 years, 0 months to 5 years, 0 months, and drawn from middle- to upper-middle-class backgrounds. All attended the Stanford University nursery school. One half of the subjects were assigned at random to the verbal stimulus condition and the rest to the pictorial stimulus condition, with the constraints that the groups be equally divided by sex and age. The mean age in the verbal group was 4 years, 5 months, and in the pictorial group, 4 years, 7 months.

Stimuli. A list of seven common objects served as stimuli: car, dog, hand, house, shoe, sink, and watch. In the pictorial condition, colored pictures of the items in a natural setting were provided on 4 × 6 in. (10 × 15 cm) cards. The objects were selected from the previous studies except that dog replaced rabbit or horse.

Procedure. Subjects were tested individually in one 15-min session. The task was introduced by the experimenter, a female graduate student, by explaining that this was a game about the parts of things, and that the experimenter would name an object and then the child would be asked to tell all of the parts of the object. In the verbal stimulus condition, for each object, the experimenter said, "Think about a (name of object). What are the parts of a (name)?" In the pictorial condition, the experimenter presented the picture and said: "Here is a (name of object). What are the parts of a (name)?" The experimenter responded positively with "Good" or "That's a good list," and gave encouragement by asking, "Can you think of any more?" The stimuli were randomized for each subject.

Correctness of part ratings. The "correctness" of the parts was assessed in a separate study. For each object, all parts mentioned by at least one child were listed in random order on a page. Twelve adult raters were asked to judge which items they considered to be parts of the object. A lenient criterion (seven or more judges) was used to determine which items would be considered correct parts of the object.

Results

Acceptable parts included those that the child described verbally or by gesture as well as those actually named. For example, "the thing that sets the time," "the thing that winds the watch," and "the round button on the side" were all acceptable descriptions of the stem of a watch. Table 9 presents the average number of correct and intruded parts for each object under verbal and pictorial presentation. More correct parts than intrusions were produced, $F(1, 46) = 8.62$, $p < .005$, and more parts of both types were produced under pictorial presentation, $F(1, 46) = 8.55$, $p < .005$. In both conditions, the intruded parts were on the whole identical to the thematic completion errors in the first two experiments (e.g., "water" for *sink*, "leash" for *dog*, and "people" for *car* and *dog*).

Discussion

Four-year-olds were asked to produce parts of objects, cued either by the object's name or by its picture. Not surprisingly, they produced more parts when cued by a picture than when cued by a name. More surprisingly, they also produced thematic completions or parts of the typical scenes of the objects in addition to actual parts. Although the objects have many parts, when cued by a label, children at this age produced an intrusion

Table 9
Average Number of Object and Intruded Parts Produced Under Verbal and Pictorial Conditions

Measure	Verbal	Pictorial
Object parts	3.24	3.97
Intruded parts	0.52	1.02

for every six genuine parts. When the cue was a picture of an object in a typical setting, children produced nearly twice as many thematic completions, indicating that the presence of context does not facilitate discrimination of an object from its setting. Rather, such pictures seem to encourage thematic associations. Thus, even in a task directly assessing knowledge of parts with no pressure to produce more responses, young children sometimes produce context parts as if they were object parts.

On the whole, the kinds of parts produced by children were similar to the parts produced by adults, although the numbers produced were fewer. For *watch,* the most frequent parts mentioned were hands, numbers, and stem; for *sink,* faucet, water (not a proper part), and drain; for *dog,* ears, tail, mouth, eyes, nose, legs, feet, and fur; for *car,* wheels, steering wheel, engine, seats, windows, doors, and roof; for *shoe,* laces, sole, and buckle; for *house,* roof, windows, door, and chimney; and for *hand,* fingers, palm, and fingernails. In general, these parts are perceptually salient (i.e., relatively large or distinct) as well as functionally significant.

The final three experiments have explored children's knowledge of parts. In the first of these, a small but functional part of a common object was missing. Young children frequently failed to detect the missing part. Performance improved dramatically with age. On the whole, children were more successful at detecting larger missing parts than smaller ones, and parts affecting canonical shape than internal parts, indicating that perceptual salience of parts is important in their detection. It is interesting to observe that children begin to perform well at the "what's missing?" task at about the same age at which they perform well at superordinate taxonomic categorization.

The most common error children made was to substitute a part of the typical context of the object for an actual missing part. For the missing screw of the scissors, children offered "paper," and for the missing rung on the ladder, children said "paint can." This same kind of error appeared as intrusions when other children were asked to produce parts of common objects. It is possible that young children have some difficulty thinking separately about the parts of an object and the parts of the setting in which the object typically appears. Children typically experience objects in natural contexts where information about the object and about the setting are interwoven. It is also possible that the young children are not carefully monitoring their own responses, and do not inhibit these highly available thematic associations when asked to produce parts. Whatever their origin, perceptual salience seems to be important for intruded parts as well; the thematic intrusions were, on the whole, larger than the actual missing parts. Put together, these findings emphasize the importance of perceptual salience in young children's knowledge about parts of objects. Johnson, Perlmutter, and Trabasso (1979) found similar perceptual factors to be operative in the acquisition of body-part terms.

General Discussion

A general framework for partonomic knowledge was presented, followed by five exploratory experiments. These experiments, along with a few others reviewed or to be reviewed, represent the beginnings of research into partonomic knowledge in children. Taxonomies and partonomies are two different but related ways of organizing knowledge. Both form hierarchies based on a transitive, asymmetric relation, *kind of* in the first, and *part of* in the second. In taxonomies of common objects and organisms, the basic-level of abstraction has a special status. It is also a level at which information about parts is salient and that naturally lends itself to either partonomic or taxonomic organization. Although preschool children readily form taxonomic groups at the basic level, they do not readily group taxonomically at a more abstract level. One of the difficulties that children may have in superordinate grouping is that superordinate categories are typically based on function alone and not on both function and appearance, as are basic-level categories. Because parts are at once components of appearance and of function, children may group members of superordinate categories sharing parts more readily than category members not sharing parts. This was demonstrated in the first study. It is possible that attention to parts facilitates the transition from the perceptually based categorization of the basic level to the functionally based categorization of the superordinate level.

Just as some category members are better or more typical exemplars of categories than others, some parts of objects are better parts than others. Parts rated high in goodness by adults tend to be both perceptually salient and functionally significant. The importance of perceptual salience for children was demonstrated in the second, third, and fourth experiments, in which children detected missing parts of common objects. In Experiment 2, children detected a part missing from the portrayed contour of an object far faster than a missing internal (but visible) part. In Experiments 3 and 4, young children often failed to report missing parts of objects when the parts were small but functional. Large missing parts were more frequently noticed. Moreover, instead of naming the actual missing part and instead of saying "nothing's missing," preschoolers tended to supply a part that was both relatively larger than the missing part and drawn from the setting in which the object typically appears. When a door was missing from a house, for instance, children said the fence around the yard was missing or the children playing in the yard were missing. Such thematic completion errors also occurred when children were asked to produce parts of objects. Both location and size of missing parts, then, affect their detection. In partonomies as in taxonomies, young children appear to be affected more by perceptual information than by more abstract functional information.

Put together, these experiments suggest that children are sensitive to parts of common objects, particularly larger parts and those on canonical object contours. They appear to be able to use this information in grouping objects into abstract, function-based superordinate categories. With these findings in mind, let us return to the general framework of partonomies from which we began. For unfamiliar objects or concepts, then, perceptual salience, in the form of size or contour discontinuity (Biederman, 1985; Hoffman & Richards, 1984), for example, may be used to segment objects into parts; the separate parts may then be used to generate hypotheses about function (Tversky & Hemenway, 1984). Other assumptions may be implicit in this sort of analysis: that different parts have different functions, that similar parts have similar functions, and that large parts have important functions. Thus, an extraterrestrial being, with a cognitive system similar to ours, may, in trying to comprehend Homo sapiens, decompose a human first into head, trunk, arms, and legs (Andersen, 1978) based on the perceptual salience of these parts. It may assume that arms and legs, because of their perceptual similarity, function more similarly than do head and arms, for instance, and that these parts are more important than smaller ones, such as kneecaps and earlobes. In some cases, the perceptual appearance of the parts themselves may suggest functions: Long parts may be used for reaching, lower parts for support. Naturally, these initial assumptions may be erroneous; they have the status of working hypotheses to be tested against experience.

Both taxonomic and partonomic forms of organization are appropriate for concepts more abstract than common objects and organisms. Professions constitute a familiar taxonomy, with divisions into white collar, blue collar, and unskilled, each of which can be subdivided into further kinds. Forms of government may be divided into democracies, dictatorships, and monarchies, and each of these into subkinds. A particular kind of government, in contrast, may form a partonomy. As every U.S. student who has studied civics knows, the American government has three branches—a legislative, an executive, and a judicial branch. Each part has separate functions and can be subdivided into smaller parts, distinguished by function. Similarly, universities are divided into faculty, staff, and students, and each of these large bodies into subgroups. Schemas, such as scenes and scripts, knowledge structures presupposed in the study of comprehension, also have a partonomic structure (Mandler, 1979). Spatial schemas, such as of objects or scenes (Tversky & Hemenway, 1983), naturally separate into parts. Temporal knowledge structures, such as scripts, also decompose into parts with natural boundaries and high consensus (e.g., Abbott, Black, & Smith, 1985; Bower, Black, & Turner, 1979); the restaurant script, for example, is divided into scenes, such as the ordering scene or the paying scene, and each of these has its own subcomponents. In these cases, together, the parts form a whole, held together by temporal or spatial relations.

Some areas of knowledge lend themselves to a partonomic organization, some to a taxonomic organization, and some to both. Anthropologists may be interested in different kinds of people, whereas medical researchers are interested in their different parts; a car salesperson may be an expert on different kinds of cars, whereas a mechanic may be an expert on different parts of cars. For familiar, culturally universal categories, both forms of organization seem to be especially salient at the basic level. Superordinate categories such as furniture or clothing are not easily decomposed to parts, although they are readily subdivided into kinds. Similarly, subordinate categories are easily decomposed to parts but are not readily subdivided into well-established kinds. For common categories, the basic level seems to be the highest level of abstraction in which both partonomic and taxonomic organizations are feasible.

Partonomies and taxonomies are products of different but complementary modes of investigation. A partonomy can be established from a single instance or object, whereas a taxonomy depends on comparison and contrast of several instances. A partonomy is a consequence of an analytic attitude, of a top-down investigation, in which a whole is decomposed into parts on the basis of relative integrality. In contrast, a taxonomy is a consequence of a synthetic attitude, of a bottom-up investigation in which exemplars are grouped on the basis of common and distinctive features. A partonomic analysis reveals subcomponents and the relations among them, whereas a taxonomic investigation reveals features shared by a number of instances and their range of variability. In some areas of knowledge, both partonomic and taxonomic forms of organization of knowledge may be useful but difficult to coordinate. In the study of history, for example, both organization by part, for instance, country, and organization by kind, for instance, political, social, or intellectual history, are compelling. To complicate matters, a second partonomic organization, by time, is also useful. Most history textbooks attempt to present all, but with considerable backtracking, repetition, and cross-referencing. In biology, too, attempts to learn parts, nervous system, circulatory system, and digestive system, depend on kinds, or species, and an understanding of kinds rests on parts. Not only textbooks and courses have to cope with integrating taxonomic and partonomic organizations, but so do general purpose information stores, such as libraries, human memories, and the Yellow Pages. The organization of different organizations of knowledge is no simple matter.

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Received February 1, 1988
Revision received February 3, 1989
Accepted April 6, 1989 ■