Developmental Psychology
1977, Vol. 13, No. 4, 299–313

Building a Tree Structure: The Development of Hierarchical Complexity and Interrupted Strategies in Children's Construction Activity

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Hierarchical tree structures occupy an important place in both linguistic theory and the psychology of language. Our study examined the construction of a tangible tree structure—a mobile made of plastic construction straws—in order to study the development of tree representations in a domain other than language. We focused on two structural principles important in language: complex hierarchical organization and interruption of constituents. Our results show systematic growth in the representation of hierarchical complexity from age 3 on. Once the basic hierarchical structure of the mobile is mastered at age 6, there is a steady increase in the interruptedness of construction strategies up to age 11. These findings confirm our hypotheses and parallel observations of language development, thus supporting the notion of a level of cognitive organization common to language and action. Our results also provide new information on the development and nature of complex action patterns.

Hierarchical tree structures occupy an important place in both linguistic theory and the psychology of language. Our study examined the construction of a tangible tree structure—a mobile made of construction straws (Figure 2)—in order to study the development of tree representations in a domain other than language. This study was part of an ongoing attempt to investigate the use of structural principles from language in the domain of action (Goodson & Greenfield, 1975; Greenfield, Nelson, & Saltzman, 1972; Greenfield & Westerman, in press). From one perspective, this is an attempt to analyze the organization of complex, sequential behavior in terms of Lashley's (1951) notion of the syntax of action as "a generalized pattern imposed upon the specific acts as they occur" (1951, p. 119). Goodnow and Levine (1972) used this notion of syntax in a developmental study of children's copying.

On a theoretical level, the development of hierarchical organization is central to Werner (1948). Werner states that "childlike actions exhibit relatively little articulation, not only because of their global character, but also because they are more or less lacking in hierarchic organization" (p. 207). This lack of hierarchic organization leads to the "chain type" of action involving repetition of individual moves. "The steps in such a continuum of action stand as parts with a homogeneous interchangeable value, since they are not at all subordinated to the final goal . . . Any one part is equal to any other so far as the character of the action is concerned. Indeed, a single part may, *pars pro toto,* represent the whole." Although it is difficult to tell in a particular situation whether Werner would claim the primitive stage to consist of a global, undifferentiated

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Our thanks go to Wanda Wong and Christine Hodson, who helped with data analysis. We are grateful to Ira Pohl, Information Sciences, University of California, Santa Cruz, for an introduction to graph theory and discussion of its application to the present study. Tamar Zelniker and Cathy Dent, University of California, Los Angeles, and Frank Capell, Stanford University, provided useful comments on early drafts.

Funding for data analysis was provided by a University Research Grant, University of California, Los Angeles.

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response or a homogeneous repetition of parts, the final stage of hierarchical integration is clear.

In Piaget and Inhelder's (1956) discussion of infralogical development, the ambiguity of the earlier stage becomes integral to a theoretical formulation. They state that the preoperational child may concentrate on a part or on the whole but cannot see simultaneously parts in relation to a whole. Vereeken (1961) has a similar theoretical view formulated specifically to account for the development of what he calls complex "constructive-praxic" behaviors (i.e., blockbuilding, drawing, copying spatial arrays, etc.). Vereeken's three levels are an extension of Piaget's model of concrete operational development. During the first level, termed "pre-conceptual," the child has only a vague idea of a total pattern or spatial configuration and only a few characteristics (subparts) can be reproduced and these in a vague and globalistic way. "Moreover, these features cannot be coordinated and exist at the side of each other as separate entities" (Vereeken, 1961, p. 91).

At Vereeken's next developmental level, which he terms "intuitive," "the child can make an exact copy of a given configuration. Consequently, there is exact awareness of the structure. However, this awareness is still intuitive, not yet operatory" (p. 91). The final operatory level involves not only awareness, but also internal representation of the structure to be constructed, as well as a number of specific characteristics, two of which can be assessed in our task: (a) Each part keeps its independence from the whole and from other parts; (b) reversibility such that a given structure can be constructed in different directions, from varying points of departure, and its component parts added in varying temporal orders.

Sinclair (1971) has pointed to a parallel between embedded structures in language, a type of hierarchical organization, and "the embedding of action schemes one into the other, when the child can put one action pattern into another pattern" (p. 126). Indeed, Bruner and Bruner (1968) described the growth of hierarchical structure in infant motor skills such as sucking and reaching.

The first focus of our study was the development of hierarchical complexity. The idea of using a branching mobile in an experiment came from Harris' (1972) thesis, *Cognitive skills in verbal and nonverbal activity,* in which she depicts a mobile as a "tree-shaped organization" (p. 85) analogous to the hierarchical structures found in language. Harris did not, however, include mobile construction in the nonverbal activities which she studied.

Studies of children's three-dimensional constructions (Goodson & Greenfield, 1975; Wood & Ross, Note 1) reveal increasing hierarchical complexity with age, as do studies of language development. For example, on the level of syntax, a series of single words are produced by the child before they are integrated into the higher order unit of a sentence, while simple sentences precede hierarchically more complex embedded clauses (e.g., R.W. Brown, 1973; Limber, 1973; Greenfield and Smith, 1976). In the domain of three-dimensional construction, Wood and Ross investigated the development of routines for assembling a hierarchically structured wooden pyramid consisting of five square-shaped levels stacked from largest to smallest. Each of the first four levels was constructed by joining two subunits, consisting in turn of two individual pieces. Construction of the hierarchical form required by this puzzle developed gradually with age. The youngest children repetitively built subunits of the larger structure, whereas the older children coordinated these subroutines into an organized whole.

The second focus of our study was the development of strategies of construction, once the basic mobile was able to be reproduced. This question concerned the process of construction rather than the child's finished structure. The role of interruption in determining construction strategies at different ages was a major focus.

In language, center-embedded sentences are considered more interrupted than left- or right-branching ones. In the sentence *The boy who was sick stayed home* the main clause *The boy stayed home* is interrupted by the subordinate clause *who was sick.* Bever (1970) and Slobin (1971) suggest that such interruption creates cognitive complexity because the speaker or listener must remember the first part of the main clause while producing or processing the second, subordinate clause, in order later to complete the first clause. This memory load is absent from a left-branching sentence like *The boy stayed home where he belonged,* for in this sentence the first clause is completed before the second is begun.

In both language (e.g., Limber, 1973; Menyuk, 1969; Slobin & Welsh, 1973) and action (Goodson & Greenfield, 1975), children avoid producing interrupted forms where possible, younger children more than older. However, once children have mastered a particular uninterrupted structure in language or construction play, they often show competence with the corresponding interrupted form as well, when pressed to do so (H. D. Brown, 1971; Goodson & Greenfield, 1975; Sheldon, 1972, 1973).

In the Goodson and Greenfield study children from 3 to 6 years old were asked to copy a bench model constructed out of blocks, bolts, and long flat sticks. There were two ways of building the bench, one involving the interruption of subunits, the other not; the two alternative strategies are depicted in Figure 1. Most (but not all) children who could build the bench using the uninterrupted method could also do so by the interrupted method, but in a free situation, the uninterrupted strategy was strongly preferred. Thus, spontaneous performance of the interrupted strategy did not keep pace with the children's emerging competence. While interruption in language obviously introduces a memory element, interrupted units in a construction task do not in the same way. Nevertheless, in order to use an interrupted construction strategy, children must "remember" to shift their attention back to the uncompleted subunit when using an interrupted strategy. In this way, interruption requires a temporal patterning of attention that parallels the memory requirements of an interrupted linguistic structure.

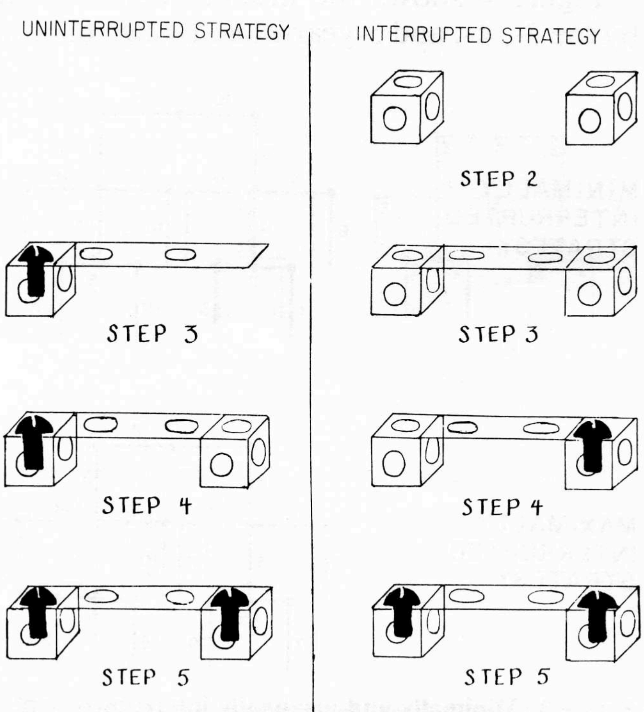

Figure 1. Action strategies for constructing bench.

The mobile construction task used in this study permitted the use of a broader range of degrees and types of interruption than the task used by Goodson and Greenfield (1975). It was, therefore, particularly suitable for further investigation of the effect of interruption on performance and competence with various construction strategies. The task also enabled us to evaluate theoretical notions about the development of hierarchical organization with new materials (construction straws) and to examine the developing child's approach to a hierarchical structure having an overt tree form. In general, we predicted that the hierarchical complexity of the completed tree mobile and the use of interrupted strategies would increase with age. A pilot study of 46 children between 3 and 11 years of age had supplied an empirical basis for these predictions. A more important objective of the present study, however, was to elucidate *how* hierarchical complexity and skill in coping with interrupted structures develop with age.

Method

Subjects

Seventy middle-class white children between the ages of 3 and 11 participated in this study. There were ten children at each of the following ages: 3, 4, 5, 6, 7, 9, and 11. Each age group was evenly divided between boys and girls.

Procedure

The task set for the children was to build a mobile from Constructo Straws, a commercially available set of flexible plastic construction straws and connectors. Each child worked individually at a table holding separate piles of red plastic straws, four-pronged red connectors, and red straws with connectors in the middle. Hanging in front of the child was a mobile made of exactly the same set of construction straws. The experimenter asked the child to build a mobile just like the one hanging in front of her or him, using the straws and connectors on the table. The experimenter demonstrated how to join the straws with the connectors. Figure 2 shows the model mobile. While the child was building the mobile the experimenter was recording the order in which pieces were added, as well as any deviations from the model. Various encouraging probes were used to maximize the performance of all the children. The 3-, 4-, and 5-year-olds were all somewhat hesitant about whether or not they would be able to complete the task. Often they said they couldn't or didn't want to do it. When this happened, the experimenter suggested, "Just build as much of the mobile as you can." With those children who hesitated further, the experimenter asked the child to stand up and point to the part of the mobile he or she was going to build. If the child stopped after connecting only a few straws, the experimenter would ask, "Does yours look like this one?" "Can you make yours look like this one?" "Now what do you have to do to finish?" and so on. With the older children who were anxious about the testing situation, the experimenter would add, "I know you can build this. I just want to see *how* you do it." The 3-, 4-, and 5-year-olds whose constructions deviated greatly from the model were asked whether they thought they had built the mobile. If they answered affirmatively, they were asked to build a part of it. This request was to see if the child had a concept of the subunits of which the mobile was composed. Through these questions we hoped to assess the relation between the child's construction behavior and his or her verbal conceptualization of this behavior. For the 6-, 7-, 9- and 11-year-olds who generally completed an exact or very close replica of the model, the experimenter asked, "Is there an easier way to build the mobile?" and then "Is there a harder way to make the mobile?" (Unless otherwise noted, however, all results are based on the children's spontaneous first constructions.) Our expectations were that the easiest way would involve minimal interruption of component parts, branches and ⊓-shaped levels within a branch, whereas the hardest way would involve maximum interruption. Figure 3 shows examples of minimally and maximally interrupted strategies. In the minimally interrupted strategy, each ⊓-shaped level is completed before going on to the next one and one branch is totally complete before the second is begun. As Figure 3 shows, this is accomplished by building the mobile as a continuous chain, up one branch, across the connecting unit, and down the other. In contrast, the maximally interrupted strategy involves constant alternation between ⊓-shaped levels in different branches, as Figure 3 shows. Thus, there is interruption not only of branches, but also of levels within a branch. Because the child must return to each interrupted subunit, level or branch, until it is completed, it was thought that this strategy would place the heaviest burden on the information processing capacities of the child and would therefore be the most difficult. If a 6-, 7-, 9-, or 11-year-old child did not come up with "easier" and "harder" strategies alone, the experimenter modeled them, asking the child to do each one in turn. (The criterion for the "harder" strategy was interruption of at least one branch and one level.) The reason for this procedure was to distinguish underlying competence from mere preference for a particular type of strategy.

A scoring diagram similar to those shown in Figure 3 was used to record the child's final approximation to the model and the order in which the various pieces were added.

Results

Final Structures: The Growth of Hierarchical Complexity

Figure 4 shows the mobiles constructed by the 3-, 4-, and 5-year-olds. By age 6, only

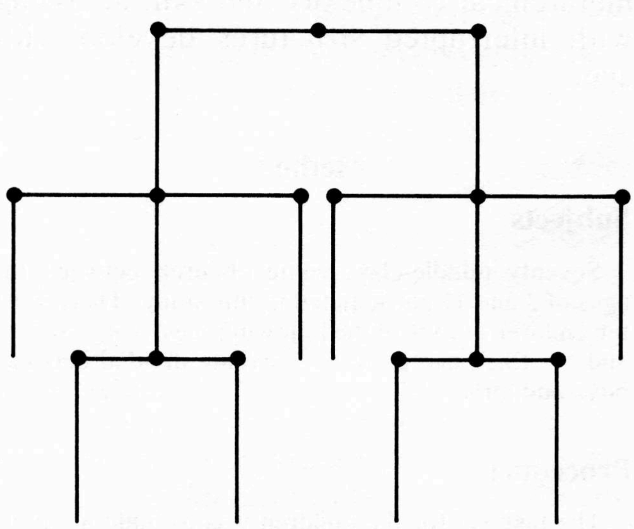

Figure 2. The model.

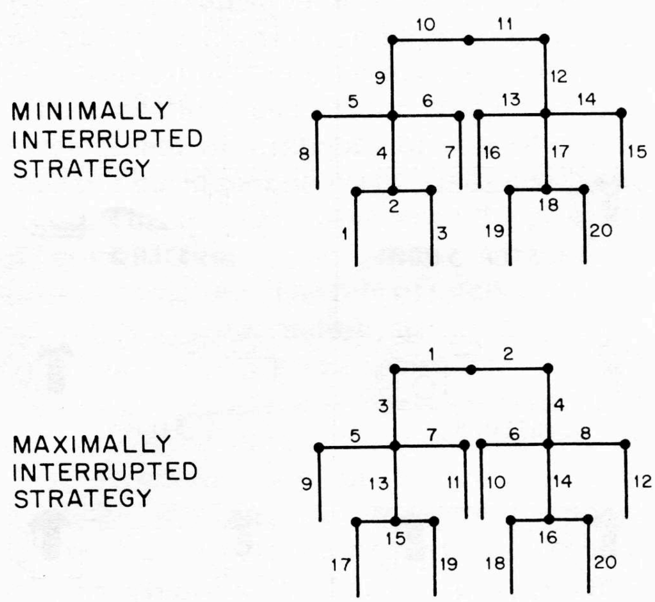

Figure 3. Minimally and maximally interrupted strategies for constructing mobile. Numbers indicate order of placement.

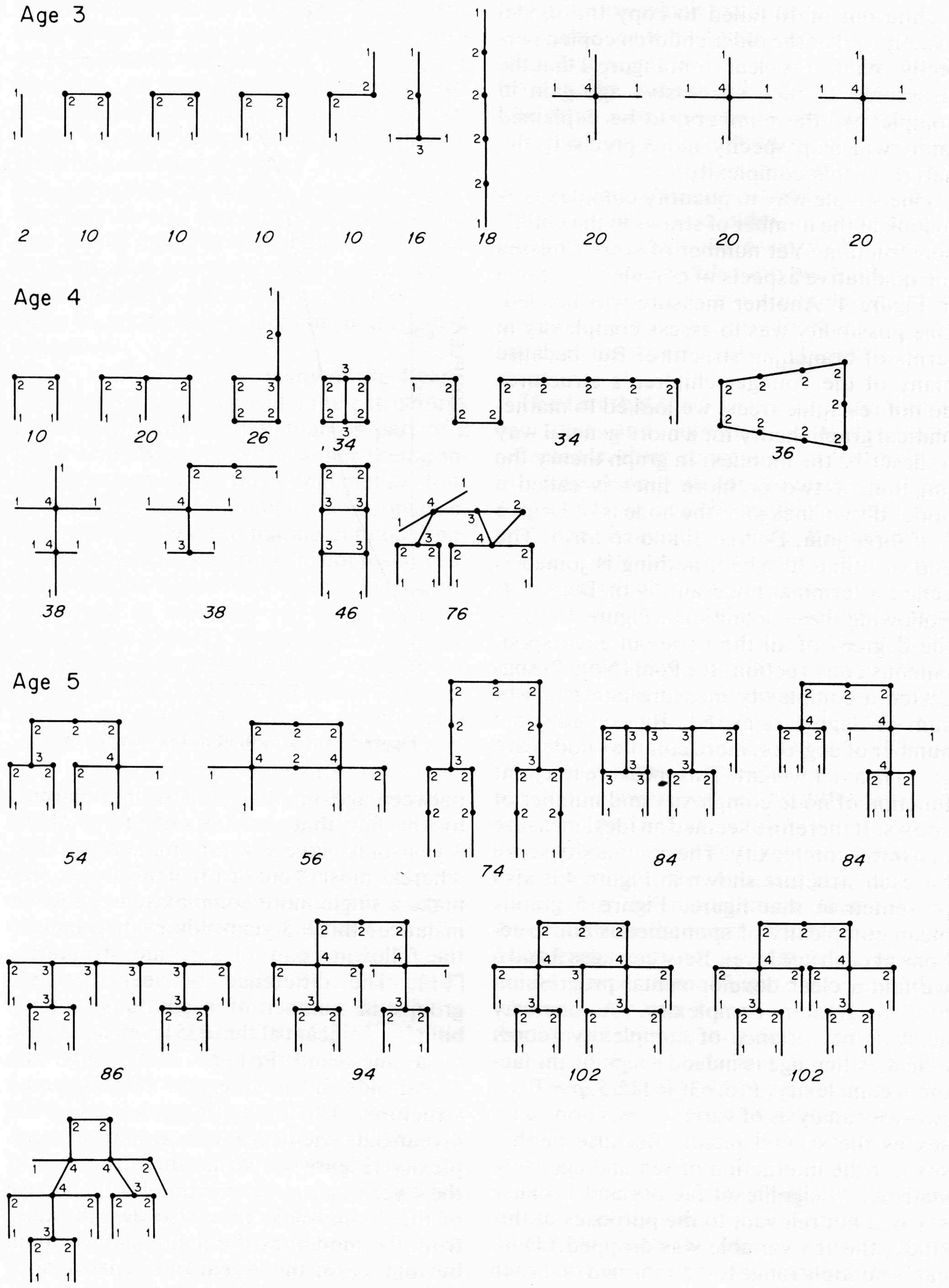

Figure 4. Mobiles constructed at ages 3, 4, and 5. If a child constructed two or more separate structures, his or her most complex one is shown in the figure. Numbers within the structures indicate the degree of each node. The rows of italicized numbers show overall complexity.

1 child out of 10 failed to copy the model exactly. All of the older children copied perfectly. While it is clear from Figure 4 that the structures at each successive age gain in complexity, the numbers, to be explained later, will help specify more precisely the nature of this complexity.

One simple way to quantify complexity is to look at the number of straws in the child's construction. Yet number of straws misses the qualitative aspects of complexity shown in Figure 4. Another measure was needed. One possibility was to assess complexity in terms of branching structure. But because many of the younger children's structures do not resemble trees, we looked to mathematical graph theory for a more general way to describe the mobiles. In graph theory the junction of two or more lines is called a node. If two lines join, the node is of Degree 2; if three join, Degree 3; and so forth. The end of a line to which nothing is joined is called a terminal node and is of Degree 1. Following these definitions, Figure 4 shows the degrees of all the nodes in each spontaneous construction. Ira Pohl (Note 2) suggested a complexity measure consisting of sum of degrees squared. By squaring the number of degrees, more complex nodes are given heavier weight. This measure is a joint function of node complexity and number of straws. It therefore seemed an ideal measure of overall complexity. The complexity score for each structure shown in Figure 4 is also presented in that figure. Figure 5 graphs mean complexity of spontaneous constructions at each age level. Between ages 3 and 6 we find a clear developmental progression toward greater complexity. A one-way analysis of variance of complexity scores indicates that age is indeed a significant factor in complexity, $F(6, 63) = 115.5, p = 0$. (A two-way analysis of variance was done with sex as the second factor. Because neither sex nor the interaction of sex and age were statistically significant factors and because sex was not relevant to the purposes of this study, the sex variable was dropped.) Duncan's multiple range test confirmed that each age group up to the 6-year-olds had created significantly more complex structures than the next younger one ($p < .01$, one-tailed).

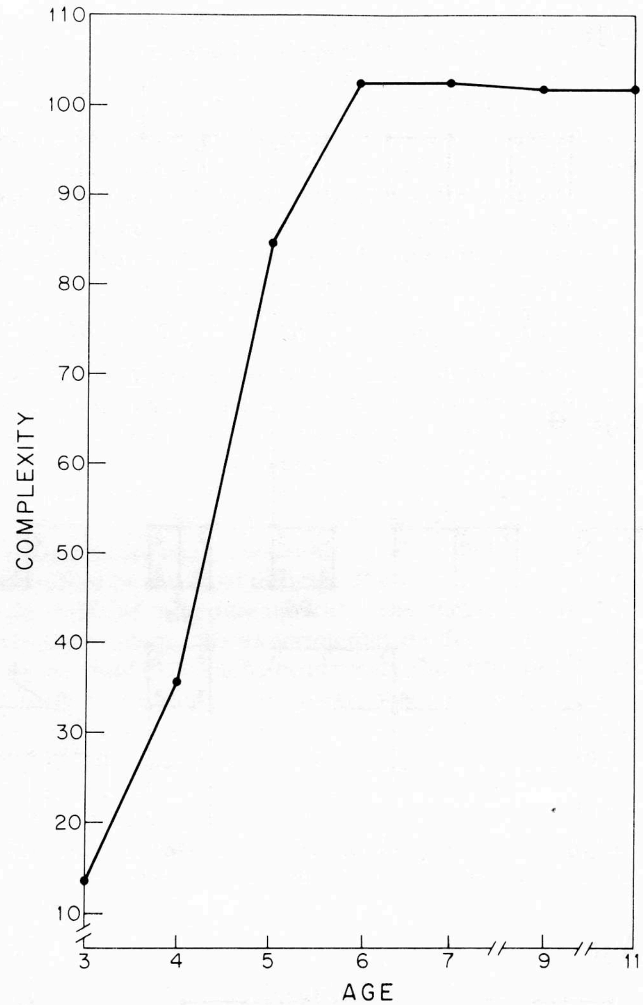

Figure 5. The growth of mobile complexity.

The nature of the developmental change between age 3 and age 4 is further clarified by the fact that most (8 out of 10) of the 3-year-olds make several simple structures, whereas most (8 out of 10) of the 4-year-olds make a single more complex structure. For instance, three 3-year-olds each produced the following pair of separate structures: ⊓ ⊓. The difference between the two groups in number of separate structures built is significant at the .025 level, according to a one-tailed Fisher's test. Thus, the 3-year-olds fail to integrate their separate structures. The integration achieved by the 4-year-olds yields greater structural complexity (Figure 4). While the structures of the 4-year-olds are more complex than those of the 3-year-olds, they also deviate more from the model, as the figure shows. In all but one case, the 3-year-old constructions reproduce actual parts of the mobile, although as Figure 4 makes clear, several different parts are selected by the various children.

It seems, however, that the 3-year-olds themselves did not consider the structures they produced as subunits but rather as complete units in and of themselves, totally unrelated to any longer range, more hierarchical plan of action. When the children were asked whether they had built the (whole) mobile, three didn't respond to the question at all, three answered yes but didn't build a part of the mobile when asked to do so, and four named some other complete structure which they felt they had made (e.g., flower, telephone pole, half a square).

Like the 3-year-olds, many of the 4-year-olds also seemed to consider their structures as complete units rather than as part of a larger unit. When asked whether their construction looked like the model mobile, four of the children maintained their constructions did look like the mobile but could not build a part of it, one child did not respond at all (although objectively there was no resemblance at all), and one child said his looked like a park. Unlike the 3-year-old group, however, one child recognized her mobile as different from the model and one child recognized his as representing but a part of the model. A third child who originally said her mobile looked like the model recognized it as a part upon further questioning. Yet another child thought his looked like the model, but was able to build a smaller part. Thus some 4-year-olds show an ability to compare structures and to analyze wholes into their component parts.

Do the 4-year-olds differ from the 5-year-olds merely in the number of straws used? Inspection of Figure 4 indicates that this is not the case. Nine out of 10 of the 4-year-old children make structures in which subparts (e.g., + or ⊓) are combined— often reiteratively—in a single branch. All 10 of the 5-year-olds, in contrast, form double-branched structures. In this task, a double-branched structure is distinguished from a single-branched one by the fact that it includes a superordinate component which joins two substructures. To be considered superordinate, a component must both join two substructures and be constructed on a (physical) plane distinct from the plane common to the subordinate parts. It is this last criterion which excludes several of the structures made by 4-year-olds (e.g., second from last 4-year-old structure in Figure 4) from being considered double branched. The difference between the two age groups in the number of children making double-branched structures is significant at the .005 level according to a one-tailed Fisher's test. Whereas the 4-year-olds integrate simple units into a chainlike form with complex nodes, the 5-year-olds form two such chains and integrate them into a double-branched structure. Here, the growth of complexity involves the diversification of a hierarchical tree.

The fact that the 5-year-olds were able to construct and join two branches was reflected in their conception of the mobile. In comparison with the younger children, 5-year-olds viewed the mobile as one large unit less frequently—more frequently as smaller units somehow connected. When they were asked if they had built the (whole) mobile, 6 of the 10 subjects answered yes; however, 4 of those 6 were then able to build a component part when requested to do so. The remaining four subjects in this group correctly observed that they had, in fact, *not* built an exact copy of the mobile. Thus, it seems that some 5-year-olds have begun to develop an awareness of the differentiation between parts and wholes while others know what is or is not a correct match.

Interestingly, the 4- and 5-year-olds deviate from the model more than do the 3-year-olds in the sense that more of them include elements not present in the original model. Inspection of Figure 4 reveals that whereas only one 3-year-old built a reproduction not entirely included in the model, 8 out of 10 4-year-olds and 5-year-olds did so. The 3-year-olds differ significantly from both the 4-year-olds and the 5-year-olds according to a two-tailed Fisher's test ($p < .01$).

The 6-year-olds as a group combine the accuracy in reproducing parts shown by the 3-year-olds with the capacity for complex hierarchical organization shown by the 5-year-olds; as mentioned earlier, 9 out of 10 6-year-olds create a perfect replica of the model. This proportion contrasts with 1 out of 10 of the 5-year-olds. Again, this difference between the groups is significant at the .005 level according to a two-tailed Fisher test. The fact that the 4- and 5-year-olds deviate from the model more than the 3- and 6-year-olds seems to indicate that, when complex hierarchical organization is in the process of developing, accuracy is temporarily sacrificed. This phenomenon is an example of "growth error" in the sense of Bruner, Olver, Greenfield, et al. (1966).

Like the 6-year-olds, the 7-, 9-, and 11-year-olds accurately reproduce the model. Hence their final structures show no new level of hierarchical complexity. All four groups differ from each other, however, in strategy; and these differences will be the focus of our next section.

Strategies for Constructing the Mobile

Whereas the previous section examined performance in terms of completed structures, the present section will focus on the *process* of construction; that is, the strategies employed by children at different ages. "Strategy" is used here in the sense of Bruner, Goodnow, and Austin (1956) as a sequence of decisions with respect to attaining some goal or end. The endpoint, in this case, is considered to be the children's final structures, described in the preceding section.

Different strategies were defined in terms of the *order* in which the child combined the straws to complete the mobile. Our analysis is concerned with alternative ways to replicate the mobile accurately and therefore concentrates on the older groups (from 6 to 11 years old) in which virtually everybody correctly reproduced the model.

The striking feature of the typical 6-year-old strategy was that it involved starting at the bottom of the mobile and working upwards. Six out of 10 used the chain strategy depicted as the minimally interrupted strategy in Figure 3, working up one side, across the top, and down the other side. Specific examples are shown in Figure 6. Among the 7-year-olds only 1 out of 10 used this strategy. Not one person in the two oldest groups used it. Significantly more 6-year-olds use the chain strategy than do the older children, according to a chi-square test, $\chi^2(1) = 12.99$, $p < .001$, two-tailed test. The dominant starting point for the older three groups was the superordinate connecting level. Excluding the one 7-year-old who used the chain strategy, we see that 28 out of 29 children started with the connecting level. This strategy implies that the mobile is being conceptually organized as a hierarchy—in terms of the superordinate and subordinate parts. The chain strategy, in contrast, does not imply this—it violates hierarchical organization by failing to progress systematically either from subordinate to superordinate parts or vice versa. It is interesting that among the 6- through 11-year-olds, not one child built both branches first, connecting them at the end. Another strategy that never occurred was to begin in the middle of a branch and work in both directions. Hence our examination of strategy reveals one additional stage after age 6 in the development of hierarchical organization, awareness of the total hierarchical structure at age 7.

We had hypothesized a developmental progression from strategies involving less interruption of subunits or subassemblies to strategies involving more. We tested this hypothesis by counting the number of shifts from segment to segment over the minimum number necessary for complete construction. A segment was defined as either a complete line or a portion bounded at each end by a transverse line. "Line" was defined topologically in that a given line would be considered as continuous even though it made a right-angle turn. The shading in Figure 7 indicates the resulting division into segments. Shifts which involved going from a segment on the left side to one on the right (or vice versa) were given double weight. The center segment was considered neither left nor right and so could not be involved in a double weighted shift. Inspection of Figure 7 shows that, according to our definitions, there are seven segments of straws, and that the minimum shift score is 6. The minimum score is obtained with the chaining strategy used by 6-year-olds (left side of Figure 6; top of Figure 3). It was thought that shifts in excess of this number would be an index of interruption of subunits, both segments and sides. This quantitative measure had the advantage over a qualitative description of

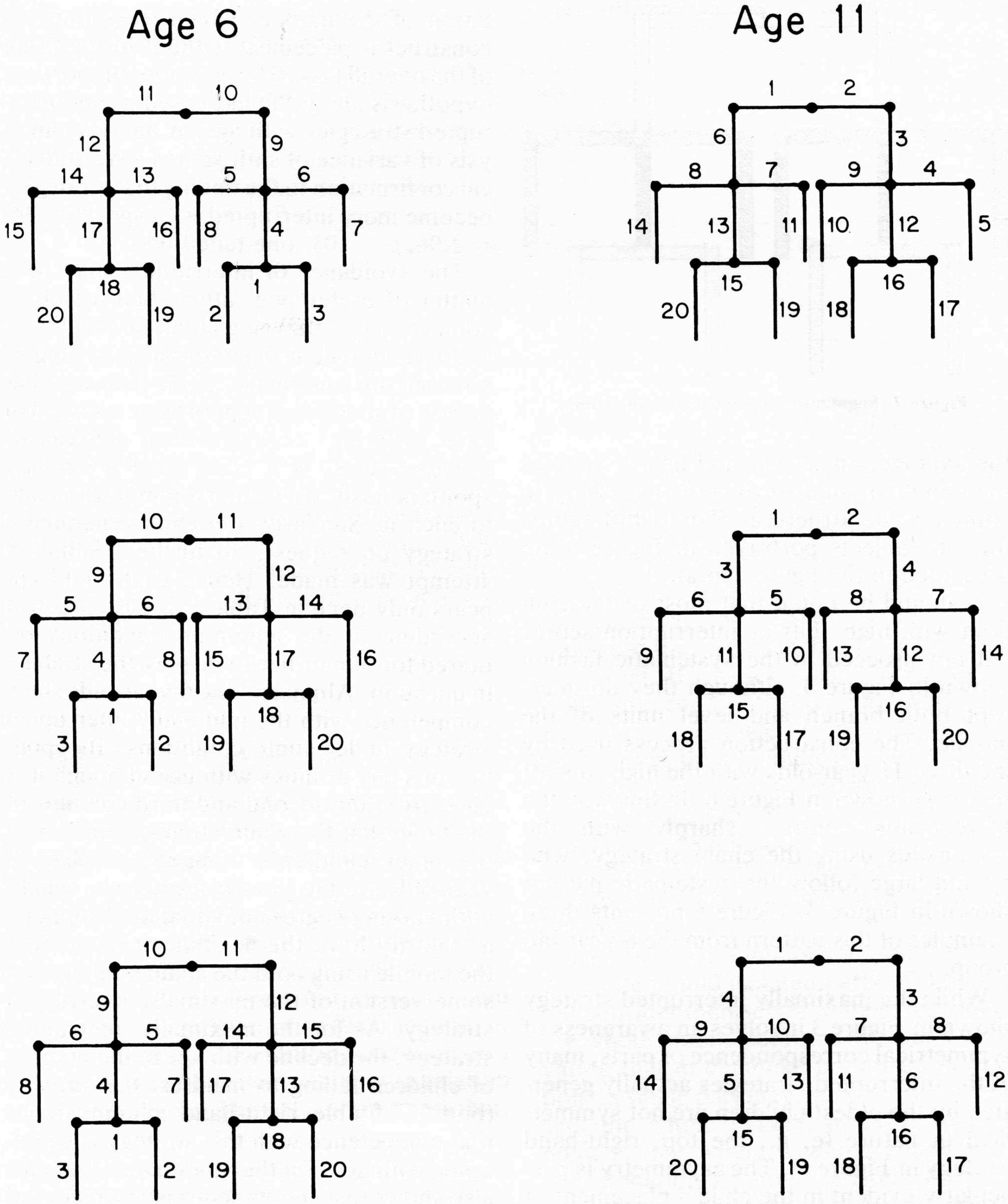

Figure 6. Some examples of minimally and maximally interrupted strategies used by 6- and 11-year-olds respectively. Numbers indicate order of placement. All of the 6-year-old strategies pictured received a shift score of 6 (the minimum score). From top to bottom, the 11-year-olds attained shift scores of 17, 17, and 15, respectively.

strategy in being sensitive to variations in degree, as well as type, of interruption. Our results show that children spontaneously use more interrupted strategies (as indexed by the shift score) as they grow older. Subtracting the minimum shift score 6 from each child's count, we find that the mean number of additional shifts is 1 for the 6-year-olds, 3.3 for the 7-year-olds, 3.5 for the 9-year-olds, and 5.2 for the 11-year-olds.[1] Thus, on

[1] Because of ambiguous data from 2 children, aver-

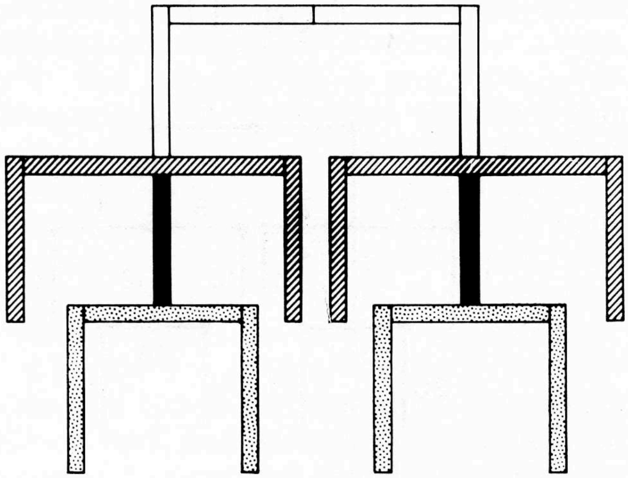

Figure 7. Segmented representation of model.

the average, an 11-year-old nearly doubles the minimum number of shifts necessary to complete the structure. (Total shift scores for the subjects portrayed in Figure 6 are presented in the figure caption.)

It should be noted that most of the children with high shift or interruption scores did not proceed in the systematic fashion shown in Figure 3, although they do interrupt both branch and level units of the mobile. The construction process used by the three 11-year-olds with the highest shift scores is shown in Figure 6. In this way the 11-year-olds contrast sharply with the 6-year-olds using the chain strategy, who by and large follow the systematic pattern shown in Figure 3. Figure 6 presents three examples of this pattern from the 6-year-old group.

While the maximally interrupted strategy shown in Figure 3 involves an awareness of symmetrical correspondence of parts, many of the interrupted strategies actually generated by the oldest children are not symmetrical in nature (e. g., the top, right-hand strategy in Figure 6). The asymmetry is particularly evident in the child's placement of straws No. 4 and No. 5. Hence, the development of interrupted strategies cannot be reduced to the development of sensitivity to symmetrical structure. The actual absence of symmetrical strategies among the oldest children using interrupted strategies may stem from a stronger internalized representation of the mobile, which frees them to construct it piecemeal without losing track of the overall task. These results support our hypothesis about the increased use of interrupted strategies with age. A one-way analysis of variance of shift scores gave statistical confirmation to the finding that strategies become more interrupted with age, $F(3, 34) = 2.96, p = .05$, one-tailed test.

The avoidance of interruption may be a matter of preference rather than a lack of competence. Analyzing children's ability to build the mobile using alternative strategies tests out this possibility. Table 1 shows what degree of situational support was required to elicit different strategies from children of different ages. If a child used a strategy spontaneously, no further attempt was made to elicit it. Similarly, if a child generated a strategy on request, no further elicitation attempt was made. Hence each child appears only once in Table 1 and is classified according to the minimum conditions required for him or her to display the strategy in question. Almost all the 6-year-olds show competence with the minimally interrupted strategy under some conditions. Its spontaneous use declines with age although it is clear from the second and third columns of the table that the chain strategy remains in the older children's competence. The 9-year-olds are the youngest group in which, with varying degrees of situational support, a majority have the flexibility to construct the mobile using both the chain strategy and some version of the maximally interrupted strategy. As for the maximally interrupted strategy, the decline with age in the number of children failing to manifest the strategy (bottom of table, right-hand column) shows that competence with this strategy is developing with age. On the other hand, the table also shows that spontaneous performance of the maximally interrupted strategy lags greatly behind competence. For instance, only five 11-year-olds use the maximally interrupted strategy spontaneously, although all ten children in this group show themselves competent to do so.[2] Thus, we find

age shift scores are based on 9 rather than 10 subjects for the 6- and 7-year old groups.

[2] An auxilary group of 10 adults, 5 males and 5 females, was also tested with the mobile to see how their strategies compared with those of the 11-year-olds. The

Table 1: Number of Children at Different Ages Requiring Different Degrees of Situational Support to Produce Two Different Strategies

Age	Used Spontaneously	Generated on request	Copied correctly	Not done
		Minimally interrupted strategy (Chain)		
6	6	0	3	1
7	1	1	5	3
9	0	4	6	0
11	0	5	5	0
		Maximally interrupted strategy		
6	0	0	2	8
7	3	1	2	4
9	2	1	5	2
11	5	2	3	0

Note. Increasing situational support was required from "Used spontaneously" to "Not done."

that even after the capacity to use a maximally interrupted strategy has developed, such a strategy may be avoided where possible. If it is the case that interruption places a strain on information processing capacities, then we have here evidence, in some children, of the operation of a principle of least effort.

Discussion

Relation to the Work of Heinz Werner

Children's mobile representations show increasing hierarchical complexity from age 3 to age 6. The earliest reproductions (at age 3) are repetitions of basic parts in the model. These parts are generally constructed separately and are not joined. These characteristics resemble the constructions of Wood and Ross's (Note 1) 3-year-old subjects, and they also fit with Werner's (1948) account of the young child concentrating attention on a single move rather than seeing it in relation to a larger whole. The only difference is that, in our task, the parts in question (e.g., + or ⊓) are themselves complex, requiring more than a single move. It is Werner's chainlike action on a higher level of development. At the next stage (age 4) there is integration of the elements of the earlier stage as children construct multi-level chains (e.g., ╪). The final stage (age 5) involves hierarchic integration of the two branches by a superordinate level. It was not clear a priori that ╪ would precede ⊓; that is, that levels would be added to a single chain or branch at a younger age than a simple double-branching structure would be constructed (both of the above contain the same number of straws). The fact that such is the case is a confirmation of Werner's claim that chainlike repetition of elements precedes hierarchical integration.

The fact that some of the youngest children often build isolated parts of the model but consider themselves to have reproduced the whole mobile confirms Werner's observation that in chainlike organization of action "a single part may, *pars pro toto,* represent the whole" (1948, p. 210). Werner's point is that where a whole consists of a concatenation of homogeneous elements, this conceptual homogeneity may also be extended to the whole itself. This conception of part as whole also indicates how difficult it is to separate out a global approach to representation from one involving a single isolated part.

Probably the nature of the medium determines which approach will constitute the primitive level of organization. Because individual construction straws must be joined

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results were essentially the same: 5 out of 10 used some version of the maximally interrupted strategy, while all the rest showed themselves competent to use this strategy when requested to build the mobile a "harder" way. Unlike the 11-year-olds, none of the adults needed to have the maximally interrupted strategy modeled in order to produce some version of it. The shift scores of this group on their first, spontaneous strategy also resembled those of the 11-year-olds. The adults averaged 5.5 above the minimum shift score.

The only unique aspect of the adult group is that it contained one member who built the mobile from both ends upwards, constructing the superordinate, connecting level last.

to make a larger figure, a purely global approach (with no differentiation into parts) is not possible. Hence, the primitive level of organization for this medium is the chainlike repetition of parts. If, in contrast, the child were *drawing* a model, a global representation could be accomplished with but a few lines. Olson has said that each medium "involves somewhat different sets of alternatives for which different cues, features, or information must be selected from the model" (1970, p. 184). We are extending this notion in saying that given features of a particular model may be easier or harder to reproduce depending on the medium. Global features may be easier in drawing, detailed features easier with a modular medium like construction straws.

Relation to the Work of Piaget

Even though the memory factor was reduced by having the model visible to all children during the construction process, each age group varied either in final structure or in strategy of construction. Thus, Piaget's (1951) idea that an imitation reflects as much the cognitive structure of the imitator as the characteristics of the model furnishes a valid methodological basis for our experimental technique.

Olson (1970), in further developing a theory of imitation, conceived of recognition and copying as two different performatory media, the latter requiring more features of a given model. It is for this reason, according to Olson, that children can recognize a diagonal figure before they can construct one. We have a parallel finding in the results of the present study that 5-year-olds often recognize that they had, in fact, failed to reproduce the mobile. Thus, they seemed to be able to recognize an accurate reproduction before they could produce one themselves.

Our results on hierarchical development would certainly not be in conflict with Piaget's idea that preoperational children will fix upon a part *or* a whole in analyzing a complex configuration, but will not organize simultaneously in terms of both parts *and* whole. More specific than Piaget's characterization, our results show a definite progression of focus from parts (age 3) to wholes (age 5) to parts *and* wholes (age 6).

Elaborating on the accord between our results and Piaget's ideas, we see that, as children begin to make progress in constructing the overall structure (ages 4 and 5), constituent parts decline in accuracy relative to those made by the 3-year-olds. Thus, the whole develops, but at the expense of the parts. This temporary inaccuracy in reproducing the individual parts can also be considered an error of growth (Bruner et al., 1966). By age 6, of course, children correctly reproduce the parts in relation to the total structure.

Relation to the Work of Vereeken

Our results also support Vereeken's (1961) three levels in the development of complex constructive-praxic development, although the first level is more complex and somewhat different from Vereeken's description. Recall that Vereeken has extended Piaget's formulation to construction activity. At the preconceptual level, children are said to form vague representations of isolated subparts. The 3-year-olds in our study produce a series, often repetitive, of parts of the mobile and do not connect these parts, just as Vereeken claimed. The parts, however, are precisely rather than vaguely reproduced. The 4-year-olds generally produce a larger part of the structure, a single multi-level chain, but it is only a vague reproduction of the branch occurring in the model. Thus, the vagueness of Vereeken's first level is presented in the 4-year-olds, but these are not the same children who produce separate isolated parts; this is a slight deviation from Vereeken's theory.

Nothing in Vereeken's description of levels would, however, account for the typical 5-year-old performance of reproducing the overall structure of the model but inaccurately reproducing the individual parts. The 6-year-olds, in contrast, fit Vereeken's description of the second, intuitive level, for they accurately reproduce the model, but usually can only do it by one strategy, the chain method.

Many 7-year-olds have one characteristic of the operatory level. Each part keeps its independence from the whole. This is a characteristic of the interrupted strategy in which children appear to be able to deal with each component straw individually, for they interrupt all the larger configurations which could function as units. This behavior, only present under elicited conditions in the 7-year-olds, shows that individual straws have not been lost in the larger configurations of levels or branches. The absence of the use of bilateral symmetry in carrying out the interrupted strategy, first present in the 9-year-olds, also indicates the presence of an internalized representation, another characteristic of the operatory level. That is, 9- and 11-year-old children using this strategy can move with ease from one part of the mobile to another without losing their place. If they did not have a representation of the total structure in mind while adding each individual part, this type of strategy could not be successful.

In terms of the construction process, the 6-year-olds are unique in their chain strategy, starting at one end of the mobile, building up one side, across, and down the other. This shows an absence of one manifestation of reversibility as Vereeken defines it, for the child can only work in a single direction. Almost all the children from age 7 upwards construct the superordinate, connecting level of the mobile first, followed by the subordinate branches. This superordinate–subordinate strategy implies conceptualization of the mobile as a hierarchy more than does the chain strategy of the 6-year-olds. In Vereeken's terms, this method shows greater reversibility, for the child first works down the mobile in one direction, then shifts directions to complete the other side. The 9-year-olds have another aspect of reversibility characteristic of the operatory level. That is, they show reversibility in the sense that they can produce the mobile not only by working in two different directions but also by methods involving different points of departure and different orders of elements. That is, most 9-year-olds were successful in using both the chain and interrupted strategies. This extension of Piaget's concept of the mobility of operational intelligence provides a theoretical treatment both of the chain strategy and of the fact that an ability to use alternative strategies to construct the mobile increases after 6.

Parallel to the reversibility and mobility of the operatory level is Werner's concept of the plasticity of mature behavior, which Werner appears to regard as a consequence of hierarchical integration. Vereeken does not relate his ideas to those of Werner, although he offers similar insights. Both Vereeken and Werner give general understanding of certain aspects of the developmental stages seen in our study, but neither gives us precise prediction of the particular sequence observed.

Parallels in Language Development

The systematic development of a tree structure found in our mobile construction task has many possible parallels in language development. A particularly interesting one is the following (Greenfield, Note 3): Just as the 3-year-olds build isolated parts of the mobile, so do children form isolated two-word propositions when they first begin to combine words. Parallel to the next stage in mobile construction is a stage in which two two-word propositions are uttered sequentially; it resembles constructions of 4-year-olds in which simple parts of the mobile are combined in sequential, chainlike fashion. A next step is the hierarchical integration of two two-word propositions into an embedded three-word sentence (two-word noun phrase plus verb; e.g., *My Doogle crying*). Similarly, the hierarchical integration of parts of the mobile into a double-branched structure is the final stage in the development of our tree structure.

In terms of strategies involving interruption of subassemblies within the mobile during the construction process, there is a gradual increase from age 6 to 11. While both competence and performance develop with age, spontaneous performance lags behind competence in the use of interrupted strategies. In other words, many of the older children who show themselves able to build the mobile interrupting both branches and levels within branches do not do so spontaneously. Thus, competence with interruption develops with age as Slobin (1971) has suggested, but is often greater than spontaneous performance might suggest. That these developmental trends are not task specific is suggested by similar results obtained by Goodson and Greenfield (1975) with respect to the use of interruption in a different sort of construction task—building a bench out of blocks, bolts, and a stick. This disjunction between competence in and use of interrupted strategies also appears in language development. In language, comprehension seems closer to a competence measure than production or imitation in the sense that it is possible to understand an interrupted sentence and correctly reproduce or produce its semantic content but in a noninterrupted form. For example, the 2-year-old studied by Slobin and Welsh (1973) showed an ability to comprehend a center-embedded or interrupted model sentence, at the same time distorting it to remove the interruption. An example is: Model—*Mozart who cried came to my party;* Imitation—*Mozart cried and came to my party*. Hence, children gain skill in comprehending interrupted structures before acquiring comparable skill in imitation or production. In parallel fashion, children in our experiment were able to use an interrupted strategy under certain more structured conditions before they would do so spontaneously.

An interesting question is why any of the oldest children use an interrupted strategy if it is more difficult. It could be nothing more than *funktionlust,* the principle that once a faculty is present, it will be exercised. In a larger context, this gratuitous use of interrupted strategies is clearly adaptive, for interruption of subunits might be obligatory for other tasks, even though optional for this particular one. The ability to use interrupted strategies, moreover, might well be related to the ability to sustain a complex sequential task in the face of extraneous interruption.

Conclusions

Our experiment has extended the study of hierarchical complexity (Goodson & Greenfield, 1975) to new materials and a new, more complex, form—a double-branched tree structure. In accord with our expectations, we have found systematic growth in the representation of this hierarchical structure, just as language development shows systematic growth of hierarchical forms. Once the basic hierarchical structure is mastered at age 6, there is a steady increase in the interruptedness of construction strategies up to age 11. While this finding confirms our hypothesis and parallels observations of language development, note that no exact analogy to the most interrupted strategy could ever occur in language, for it would seem to involve shifting between clauses after every word! Nor could our tree ever be used to represent a particular sentence. For example, a given sentence would be composed of differentiated elements (a variety of words) whereas our mobile consists of homogeneous elements (identical straws). These facts bring home the point that while common organizational principles may underlie language and action, the application of these organizational principles in different modalities and different domains will yield many diverse forms of behavior. It is precisely this diversity of possible application which would constitute the power of an amodal cognitive organization.

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(Received July 19, 1976)