The Development of Error Correction Strategies in Young Children’s Manipulative Play

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DeLoache, Judy S.; Sugarman, Susan; and Brown, Ann L. The Development of Error Correction Strategies in Young Children’s Manipulative Play. Child Development, 1985, 56, 928–939. The focus of this study was the strategies used by young children between 18 and 42 months for correcting the errors they made as they attempted to nest a set of 5 seriated cups. In the process of combining the cups, the children committed numerous errors (such as putting a cup that was too large on a smaller cup), and they tried to correct the majority of those errors. Detailed examination of the children’s correction attempts revealed that the strategies they used changed substantially with age, becoming increasingly more flexible and involving more extensive restructuring of the relations among the cups. Earlier correction attempts tended to focus on a single, nonfitting cup or on a single relation between 2 cups. Later-appearing strategies involved the coordination of relations involving several cups. The same trend toward increasing flexibility of thought and action also appeared in the procedures the children used to combine the cups. This study thus documents a finely graded series of cognitively significant changes in children’s constructive activity during a period that has been poorly differentiated by cognitive developmental research. In so doing, it demonstrates the usefulness for problem-solving research of analyzing how subjects go about trying to rectify their own mistakes.

To err is human. In fact, it is probably rare to solve problems through a series of perfect maneuvers. A crucial part of problem solving, of logical insight, of efficient thought in general, is the ability to overcome errors or obstacles. One has to be able to interrupt ongoing activity, back off, restructure the problem, and then go about pursuing the same goal, but in a new way.

In the present paper we examine error correction strategies of young children. We report evidence of very early developments in the restructuring process involved in the correction of errors, developments that reveal increasing flexibility of thought and action. This research reflects our belief that the error correction process is an important form of self-regulation relevant to a wide range of cognitive activities (Brown & DeLoache, 1978), and that it should undergo substantial development. Analyses of errors have been common in investigations of both language acquisition and problem solving, in which error data have diagnostic utility in identifying the rules children are using and the kind of learning process in which they are engaged (e.g., Bowerman, 1982; Karmiloff-Smith, 1979; Klahr & Robinson, 1981; Siegler, 1981; Wilkinson, 1982; Woodward, 1972). Our interest is different in that we are concerned with children’s methods of error correction, that is, with what follows their errors, rather than with the types or frequency of the errors themselves.

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To study the early development of error correction, we needed a task that would fulfill three requirements: It should elicit goal-directed effort from a relatively wide age range of children, it should generate a large data base of errors, and the errors should be detectable by the subjects. This latter requirement is important, because in many tasks, younger children are less likely than older ones to detect their own errors (Wilkinson, 1982). Accordingly, we gave 1½-3½-year-old children the task of assembling a set of nesting cups (five cups graded by size). With no inducement other than the presence of the cups, children in this age range will spontaneously attempt to combine cups and will work until they have managed, often through trial and error, to nest some or all of the cups (Greenfield, Nelson, & Saltzman, 1972; Woodward, 1972). Thus, even children as young as 18 months respond to the nesting cups as a problem to be solved: Their behavior is highly goal directed and relatively persistent, and it is motivated by their own sense of discovery and achievement.

Furthermore, in spite of their enthusiasm for the task, these young children make numerous errors in nesting the cups. More often than not, they combine cups inappropriately, placing one cup on top of a smaller cup or placing one cup inside another that is more than one size larger. The children's detection of their errors is facilitated by the nature of the materials. Nesting cups provide immediate functional feedback: Either one cup goes into another one, or it does not. If it does go in, the two cups either fit together tightly, or they do not. If the placement is incorrect, the child can feel the lack of fit and can try another arrangement, that is, try to correct the error. The functional feedback inherent in the nesting cups differentiates them from other types of materials, such as sticks of graduated lengths, that have been used in traditional Piagetian studies of seriation. This feature is crucial for enabling very young children to carry out the self-monitoring and error detection that are prerequisites to error correction attempts.

We expected that our examination of the process of error correction in the nesting cups task would illustrate the important role of self-correction in problem solving, suggesting that developmental progress in any problem domain is not simply a matter of increasing ability to avoid errors, but also of increasing ability to correct errors. In the nesting cups task, for example, previous researchers have documented improvement with age in the rate of achieving full seriation of a set of cups (Greenfield et al., 1972; Woodward, 1972). We hypothesized that this developmental increase in seriation is a function not just of increasing ability to select the appropriate cups at each point (i.e., to avoid errors), but also of increasing ability to correct errors in ordering the cups (i.e., to reorder them). We also expected that our investigation of the error correction procedures of young children would provide illuminating information about their thought processes: The scope and nature of their correction attempts should tell us not just about their ability to reorganize the relations among a set of objects, but also about their understanding of those relations in the first place.

Pilot work leading to the present study (Sugarman, 1983, chap. 12) indicated the presence of marked developmental changes in how children reacted to the errors they made in assembling nesting cups. All occasions on which a larger cup had been placed on top of a smaller one were examined, and the following sequence was observed in children's attempts to deal with the errors. The youngest subjects, at 12 and 18 months, would simply try to make the top cup fit by pressing on it, as if something were wrong with the cup. Indeed, one child went so far as to examine the bottom of one cup after trying to force it into the one below. Slightly older children seemed to see that the lack of fit had something to do with the relation between cups, rather than with the properties of a single cup. They would often remove a nonfitting cup (rather than pressing on it) and replace it with another cup, but these efforts appeared haphazard and usually did not improve the overall order of the set of cups. By 3 years of age, the children recognized not only that the relation between the cups was the problem, but that for any given cup, two relations needed to be taken into account—both how the focal cup fits into the next larger cup and how the next smaller cup fits into it.

The primary goal of the present study was to make a more systematic and detailed examination of this sequence. Thus, our primary focus was the process that ensued when a child made an error in combining the nesting cups, regardless of the outcome he or she eventually produced. In other words, we were less interested in what the child produced (whether or not he or she achieved a seriated product) than in how it was produced.

A second focus of the present study was to examine the correspondence between
young children's procedures for correcting the errors made in nesting the cups and the procedures used to combine the cups in the first place. Greenfield et al. (1972) documented a sequence of two procedures by which children between 1½ and 3 years of age combined a set of five nesting cups. With the earlier-appearing procedure—the pot method—the children brought each individual cup, one at a time, to the stack or nest they were in the process of constructing. With the later-appearing procedure—subassembly—the children combined two cups and then moved them as a unit to a new cup. The subassembly procedure was seen by Greenfield et al. (1972) as more complex conceptually than the pot method, because it involved reversing the relational role of successive cups. The stationary base cup that was the passive recipient of action in one move became the active, moving cup in the next move. The pot method did not involve this reversal of role, since each cup was simply moved, in its turn, to the stationary base (the "pot"). The use of the subassembly strategy increased with age, and reliance on the pot method decreased.

It was expected that an analysis of children's error correction attempts in this same context would allow still finer distinctions to be made concerning the children's conceptual analysis of the array. Accordingly, we gave young children a period of free play with a set of nesting cups, taking their spontaneous manipulation of the cups as a reflection of their thought processes. We examined both the children's composition procedures (i.e., the procedures used to combine cups) and their spontaneous attempts to correct the errors they made. To make sure that we observed the most sophisticated behavior of which a child was capable, two additional elicitation trials were given to provoke the use of the more complex procedures.

Method

Subjects

The subjects were 40 children, four girls and four boys at each of five ages: 18, 24, 30, 36, and 42 months. Names of the subjects were obtained through records of birth announcements in local newspapers and through local day-care centers, with both sources relied on for some of the subjects at each age. Over 75% of the parents who were contacted by telephone agreed to bring their child to the laboratory for the observation session. All subjects who participated are included in the data. The sample was predominantly middle class and white.

Materials

A set of five nesting cups served as the stimulus materials. The largest cup measured 7.8 cm and the smallest 6.6 cm, with a 0.3-cm increment between successive cups. The cups were of varied colors, but were not ordered by hue. An additional, larger (8.1-cm) cup was added for the second elicitation trial.

Procedure

The subject was seated at a large table, either on his or her mother's lap or in a booster chair with the mother seated nearby. The experimenter sat across the table facing the child. A video camera filmed the subject's activity with the cups.

Spontaneous manipulation.—To begin the session, the experimenter placed the five separate cups on the table in a random array, saying, "These are for you to play with." The children typically began to nest them immediately or in a short time without further prompting. If, after 2 min of manipulation, the child had not succeeded in completely nesting the cups, the experimenter modeled the goal state of nested cups. She put them together under the table (so the child could not see her actions), showed the child the fully nested set of cups, then disassembled them out of sight, and again presented the child with the five separate cups. If at any time the subject successfully nested the whole set of cups, the trial ended. Occasionally, a trial was terminated by a subject's refusal to continue. Throughout the session, the experimenter made occasional encouraging comments (e.g., "You're doing well") or nonspecific prompts ("Play some more with the toys"), but the child was never specifically rewarded for any product.

Elicitation trials.—Following the spontaneous manipulation phase, each subject was given two trials designed to elicit the most advanced procedures of which the child was capable. For each of the elicitation trials, half the subjects within each age group were ran-

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1 The nesting-cups task reported in this paper was given in the same session with three other seriation tasks (two sets of stacking rings and a set of ordered sticks) and an object-classification task. Before the nesting-cups task, all subjects had experienced the classification task, and some of them had also manipulated stacking rings. There was no discernible difference in the children’s performance as a function of the order of tasks they experienced. Data from the other tasks are not included in this paper, because the rate of error correction attempts was very low.
domly assigned to receive one or the other of the starting sets.

The purpose of elicitation trial A was to see if the child could alternate between the two relations "larger than" and "smaller than." The experimenter first put together two middle cups (cups 2/3 or 3/4) and handed them to the child. She then handed the other three cups, one at a time, to the child. Subjects who had been given cups 2/3 received 4, then 1, and then 5; and subjects who were initially given cups 3/4 received cups 2, 5, and 1. A fully seriated product could be realized either by the child's anticipating the correct placement of the cups as he or she was handed them (alternating between adding cups to the top and bottom of the stack) or by switching a nonfitting larger cup from the top to the bottom of the stack.

Elicitation trial B was designed to require the coordination of relations, and was similar to the "insert" trial that Greenfield et al. (1972) gave to any subject who had achieved full seriation. The subject was given a set of five cups (with cup 6 added as the base cup), completely nested, except that either cup 3 or 4 was missing from the stack. The child was then handed the missing cup. To produce a fully seriated product, the child had to disassemble the stack, insert the extra cup into its correct place in the middle, and then reassemble the cups in the correct order. We expected that this trial would be more difficult than trial A, because the subject was required to decompose and restructure an intact configuration in order to insert the new cup.

Working from videotapes, an observer transcribed every contact of any sort that each subject made with a cup or set of cups, and these transcripts were used for all of the subsequent scoring.

Results

The data reveal developmental improvement both in terms of the achievement of seriated products and in the procedures the children employed in manipulating the cups. We first present base-rate information on the children's manipulation of the cups, the incidence of seriation, and the composition procedures used to combine cups. We will then describe our findings concerning the development of correction strategies and how they relate to composition strategies. Finally, the same measures will be presented for the two elicitation trials. For simplicity in writing, we will use the singular "cup" to refer to either a single cup or to a stack or nest of two or more cups.

Spontaneous Manipulation

All the children began manipulating the cups as soon as they were placed on the table. The majority (35, or 88%) very quickly started nesting them (inserting one cup inside another), although five subjects began nesting the cups only after the experimenter showed them the set of cups all put together. To have a measure of the amount of manipulative activity that occurred, the transcripts were scored for the number of moves that each child made. A move was defined as any placement of a properly oriented cup in or on another cup. The reason for counting only upright combinations was so that we could hold constant across subjects the end product of the spontaneous manipulation of the cups and hence be more certain of what the children were trying to do with the cups. Excluded from analysis were actions such as mouthing or throwing the cups, as well as turning them over or stacking them upside down. Although in principle one could construct an ordered series by stacking the set of cups upside down, this type of activity was very rare. Including such manipulations in the analyses would not change any of the results, but it would have made the scoring system unnecessarily cumbersome.

Table 1 shows the mean number of moves for the five age groups. The overall mean number of moves per subject was 11.7 (range = 2–29, SD = 6.98), and the five age groups did not differ significantly in terms of the number of moves they performed with the cups.

Seriation.—A total of 18 (nine females and nine males) of the 40 subjects achieved full seriation of the five cups (i.e., the final product of their manipulation was 1/2/3/4/5). As shown in Table 1, the number of successful seriators increased with age (point biserial \( r = .54, df = 38, p < .001 \)), from none of the 18-month-olds to all but one of the 42-month-olds. The level of successful seriation is similar to that reported by Greenfield et al. (1972) for 28–36-month-olds.

There were also age differences in how directly full seriation was achieved. Table 1 shows the total number of moves taken by the 18 seriators to achieve full seriation. In a one-way analysis of variance of these data, the main effect for age was significant, \( F(3,14) = 3.53, p < .05 \). The 42-month-old seriators made more moves in the process of achieving seriation than did the younger age groups.
TABLE 1

**Baseline Information**

<table>
<thead>
<tr>
<th>Age (in Months)</th>
<th>18</th>
<th>24</th>
<th>30</th>
<th>36</th>
<th>42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seriation:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean no. of moves</td>
<td>11.13</td>
<td>7.50</td>
<td>11.50</td>
<td>13.25</td>
<td>15.13</td>
</tr>
<tr>
<td>No. of subjects who achieved full seriation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 40)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean no. of moves taken to achieve full seriation (N = 18 full seriators)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composition procedures:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of subjects who used pot method only</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>No. of subjects who used subassembly</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Errors:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of moves that were correct</td>
<td>.24</td>
<td>.37</td>
<td>.46</td>
<td>.37</td>
<td>.42</td>
</tr>
<tr>
<td>Proportion of errors followed by correction attempts</td>
<td>.57</td>
<td>.62</td>
<td>.59</td>
<td>.59</td>
<td>.66</td>
</tr>
</tbody>
</table>

(Received-Keuls, \( p < .05 \)), which did not differ from each other.

Another result that reflected age differences in the directness with which seriation was accomplished was the number of subjects who seriated all five cups without committing any errors in the process. Four of the 18 seriators (one 24-month-old, two 30-month-olds, and one 42-month-old) nested all the cups in immediate sequence. On each of their four moves they selected the largest available cup, nesting cup 4 in cup 5, 3 in 4/5, and so on. In addition, one other 24-month-old achieved full seriation in a sequence of five correct moves: one immediately corrected initial error followed by four correct moves. Thus, four out of the seven (or 57%) 24- and 30-month-old subjects who achieved full seriation did so in an errorless series of moves,\(^2\) in contrast to only one of the 11 (9%) older seriators. This age difference in full seriation without error was marginally significant by a Fisher's exact test, \( p < .10 \). Thus, the younger children most often achieved seriation by avoiding errors, whereas the older seriators made numerous errors but managed to correct them.

**Composition strategies.**—The transcripts were scored for the pot and subassembly procedures identified by Greenfield et al. (1972). Although formal interrater reliabilities were not computed for the composition and correction strategies, all the scoring was independently checked by three different scorers. In the pot method, one cup serves as the base cup, and the child successively places more cups, one at a time, into or onto that base cup. The defining feature of subassembly is that a previously combined stack of two or more cups is moved as a unit into or onto another cup. Subassembly was scored only when the multicup unit was moved immediately after being assembled; this constraint was imposed so that the measure would be an index of flexibility. A child who has placed cup 1 in cup 2, and then moved 1/2 into cup 3, has immediately reversed the role played by cup 2 from a receptacle to an insertable object. The child has in immediate succession considered a given cup as first one thing and then another.

Our results for composition procedures are consistent with those of Greenfield et al. (1972), both in terms of decreasing reliance with age on the pot method and increasing use of subassembly. As Table 1 shows, the number of subjects who used only the pot method and limited themselves to moving one cup at a time into or onto a central stack decreased with age, \( r_{pb} = -.39, df = 38, p < .02 \). Conversely, the number of subjects who used the subassembly procedure at least once increased with age, \( r_{pb} = .37, df = 38, p < .02 \).

\(^2\) This appears to be a higher level of perfect seriation than might be expected from Woodward's (1972) data, in which only one of 30 children below the age of 4½ selected all cups in order of size. However, Woodward used a set of 12 cups, while our subjects were only required to nest five cups. It may be that the rather precocious performance of these four children would break down with a larger set.
Error detection and correction attempts.—Every move made by a child was scored as either correct, if the two cups joined on that move were appropriately ordered and were one step apart in size, or incorrect (an error) if they were not. Thus, moving nested cups 2/3 into base cup 4 was considered correct, but putting 2/3 into base cup 5 constituted an error.

At all ages, more than half of the children’s moves were errors. The proportion of moves that were correctly seriated (the number of correct moves for each subject divided by his or her total number of moves) did not differ as a function of age (see Table 1). The main effect for age was not reliable \( F = .94 \) in a 5 (age) \( \times \) 2 (sex) analysis of variance. The only significant effect was an age \( \times \) sex interaction, \( F(4,30) = 4.41, p < .01 \), which was due to the extremely low proportion of correct moves for the 24-month-old boys.

Given that a child made an error, how likely was he or she to detect that error? For every incorrect move, or error, we determined whether the inappropriately placed cup was simply left in place or whether the subject initiated one of the error correction strategies described below. Of the 36 children who committed one or more errors, 34 (96%) attempted to correct at least some of their errors. Overall, 61% of the children’s errors were followed by correction attempts. There were no age differences in the likelihood that an error would be followed by a correction attempt (see Table 1), suggesting that all age groups were equally sensitive to the commission of errors in combining the cups. Not surprisingly, errors that involved the placement of a larger cup on top of a smaller one were more likely at every age to elicit correction attempts (80% of the time) than were errors that involved inserting a smaller cup into a cup that was more than one size larger than it (24%). The age groups did not differ in the proportion of their errors that were too big (65%) or too small (35%).

As expected, then, the children made numerous errors, thus providing a sizable database for analyzing correction strategies. There were no age differences in the mean number of moves the children made, in the proportion of those moves that were errors, in the type of errors committed, or in the proportion of errors followed by a correction attempt. Thus, the age differences in error correction strategies that are reported next cannot be attributed to unequal opportunity to employ those strategies. In other words, the differences in how children of different ages tried to correct their mistakes were not confounded with differences in their overall rate or type of error.

Correction strategies.—The major dimension of our scoring typology embodies a progression from: (a) a focus on a single, nonfitting cup (Force) to (b) a focus on the relation between the top cup and the next one down, resulting in partial or total disassembly of the stack (Decompose) or substitution of a new top cup or recipient cup (Try an Alternative) to (c) a focus on the internal relations in the stack, resulting in the reordering of the cups. At this third level, a distinction was made between rearrangements that did not improve the ordering of the cups (Rearrange) and those that did (Insert). (For nonperfect constructions, improvement was scored when the number of cups that were correctly nested increased as a result of the child’s manipulations.) This separation was made in an attempt to distinguish reordering of the cups motivated simply by a desire to put a nonfitting cup somewhere where it would go from reordering that was an attempt specifically to relate the focal cup to a larger and a smaller cup. Although the achievement of an improved ordering would not necessarily indicate that a subject had coordinated relations, an overall developmental trend from nonimproved to improved ordering would suggest increasing ability in that direction. The final category (Reverse) is similar to Woodward’s (1972) strategy 6 and is akin to Greenfield et al.’s (1972) subassembly composition strategy. A cup that the child at one moment tries to place in one relation to another cup (smaller than, insertable in) is, in the next moment, placed in a different relation to it (larger than, able to fit around).

The sequence of moves to which a correction strategy, other than Force, was assigned began with the first move following an error that involved taking apart a construction. It ended when the subject either (a) achieved full seriation, (b) began taking apart a new construction, or (c) stopped manipulating the cups. The following six correction strategies were scored:

1. Force: The subject exerts pressure in an attempt to force a nonfitting top cup into a smaller base cup. All the subject’s remedial efforts are focused on a single, nonfitting cup.

2. Decompose: Part or all of a stack of cups is taken apart and then is either left disassembled or is reassembled in exactly the same configuration (e.g., 1/2/4/3/5 \( \rightarrow \) [becomes] 1/2/4/3/5). This strategy is thus directed toward more than a single cup, but no reordering of the cups takes place.
TABLE 2
CORRELATION MATRIX FOR CORRECTION STRATEGIES

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Force</th>
<th>Decompose</th>
<th>Try an Alternative</th>
<th>Rearrange</th>
<th>Insert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>-.17</td>
<td>...</td>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decompose</td>
<td>-.34*</td>
<td>.28*</td>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Try an Alternative</td>
<td>-.14</td>
<td>.16</td>
<td>.00</td>
<td></td>
<td>.-04</td>
<td>...</td>
</tr>
<tr>
<td>Rearrange</td>
<td>.25</td>
<td>.43**</td>
<td>-.15</td>
<td>-.04</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Insert</td>
<td>-.65***</td>
<td>-.30*</td>
<td>-.40**</td>
<td>-.16</td>
<td>.25</td>
<td>...</td>
</tr>
<tr>
<td>Reverse</td>
<td>-.58***</td>
<td>.01</td>
<td>-.20</td>
<td>-.08</td>
<td>.21</td>
<td>.35*</td>
</tr>
</tbody>
</table>

Note.—The correlations of age and correction strategies are point biserial correlations, \( df = 34 \); the intercorrelations among the correction strategies are phi coefficients.

\*\( p < .05 \)
\**\( p < .01 \)
\***\( p < .001 \)

3. Try an Alternative: After moving a cup into or onto an incorrect base cup, the subject immediately removes the top cup from the base cup and (a) that top cup is moved to and placed in or on a different base cup (e.g., \( 4/3 \rightarrow 4/5 \); \( 1/3 \rightarrow 1/4 \)) (try an alternative base), or (b) the original base cup is retained and a different top cup is placed on it (e.g., \( 1/3 \rightarrow 2/3 \); \( 4/2 \rightarrow 3/2 \)) (try an alternative top). This strategy involves reordering cups, but only one relationship (between two cups) is altered.

4. Rearrange: Some or all of the cups in a stack are taken apart and put back together in a different order, but the resulting configuration is no better seriated than the original one (e.g., \( 1/2/4/3/5 \rightarrow 2/3/5/4/1 \)). Here a set of cups is reordered, but the subject fails to improve upon his or her previous product.

5. Insert: Some or all of the cups in a stack are taken apart and put back together in a different and improved (i.e., more seriated) order (e.g., \( 1/2/4/3/5 \) [1 cup correctly nested] \( \rightarrow 4/1/2/3/5 \) [2 cups nested] or \( 1/2/3/4/5 \) [4 cups nested]). Thus, the subject's reordering of the cups achieves a more fully seriated product.

6. Reverse: The subject immediately reverses the relationship between two cups that he or she has just combined. A nonfitting top cut that has just been placed in or on another cup is removed and immediately moved under the stack (e.g., \( 4/3 \rightarrow 3/4 \); \( 4/5/1/2/3 \rightarrow 1/2/3/4/5 \); \( 2/1/3 \rightarrow 1/3/2 \)). Thus, what was the top cup becomes the base cup, and the formerly base cup becomes the top cup. The immediacy constraint for reversals was adopted for the same reason as for subassembly (see Composition procedures).

Each subject was scored for the presence or absence of each of the correction strategies. Table 2 shows the point biserial correlations between age and the number of subjects who used each strategy once or more. These correlations were computed without the four subjects who achieved full seriation with no errors and hence had no opportunity for error corrections. The six correction strategies were differentially related to age. The three strategies that involve little or no reordering of the cups—Force, Decompose, and Try an Alternative—were negatively related to age, although only the correlation for Decompose reached significance.

All three strategies that do involve reordering were positively related to age, and two of the strategies showed large and significant positive correlations with age—Insert, which involved more extensive and improved reordering of the cups, and Reverse, the strategy that involved interchanging cups. As Table 3 shows, these strategies were quite rare in the younger age groups, but were displayed by over half of the older children. As the rate of error corrections did not differ across age,

TABLE 3
NUMBER OF SUBJECTS WHO USED INSERT AND REVERSAL CORRECTION STRATEGIES IN SPONTANEOUS MANIPULATION PHASE

<table>
<thead>
<tr>
<th>STRATEGY</th>
<th>18</th>
<th>24</th>
<th>30</th>
<th>36</th>
<th>42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insert</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Reversal</td>
<td>0</td>
<td>1</td>
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these results suggest that the principal developmental change was in how children attempted to correct their errors, rather than in the frequency with which they committed or detected them.

**Relationship between Composition and Correction Strategies**

In both the subassembly composition procedure and the reversal correction strategy, a given cup immediately shifts from being the active (insertable) cup to being the passive, recipient cup. Thus, one would expect these two procedures to be related to each other, and they were. The correlation (phi coefficient) between subassembly and reversal was $0.61$, $df = 34$, $p < .001$. This relationship was apparent at all ages. In fact, all but two of the 13 subjects who performed reversals also exhibited the subassembly composition procedure. In contrast, not one of the 18 subjects who relied solely on the pot method ever performed a reversal. Insert was also related to the use of subassembly, $\phi = 0.43$, $df = 34$, $p < .005$.

**Elicitation Trials**

The two elicitation trials were designed to elicit the most complex behavior of which a given subject might be capable. On elicitation trial A, this was either alternation between considering two different relations (insertable in, able to fit around) or the use of the reversal correction strategy; and on elicitation trial B, it was the coordination of relations involved in the insert correction procedure. For elicitation trial A, the child was presented with two assembled cups (either 2/3 or 3/4) and then handed the remaining three cups, one at a time. A total of 18 children (eight females and 10 males) achieved full seriation of the five cups, including 0, 2, 5, 5, and 6 children at each of the five ages. As in the spontaneous-manipulation trial, full seriation was significantly related to age, $r_{ph} = 0.53$, $df = 38$, $p < .001$. Seriation on elicitation trial A was related to seriation on the spontaneous trial, $\phi = 0.54$, $df = 38$, $p < .05$; 15 of the 18 seriators on the elicitation trial had achieved full seriation earlier. It made no difference whether a subject was started with the 2/3 or the 3/4 cup set: Nine of the full seriators began with each.

Five of the children who achieved full seriation on elicitation trial A made no errors (0, 0, 1, 1, and 3 at the five ages); that is, they anticipated the correct placement of each cup as it was handed to them, moving cup 4 or 5 straight to the bottom of the stack without first trying it on the top. Errorless seriation was significantly related to age, $r_{ph} = 0.37$, $df = 33$, $p < .02$. However, the most common method of achieving seriation on elicitation trial A was by using the reversal correction strategy. Eleven (61%) of the seriators first tried at least one of the larger cups on the top of the stack and then immediately reversed it to the bottom. As in the spontaneous manipulation phase, the use of the reversal strategy was significantly related to age, $r_{ph} = 0.46$, $p < .02$ (0, 2, 5, 5, and 5 subjects at each age).

There were two subjects who achieved full seriation on this trial without either anticipating the correct placement of each successive cup or using reversal. One of these was a 36-month-old girl who never performed a reversal throughout the experiment. To succeed on the elicitation trial, she disassembled all the cups and then proceeded to nest them, via the pot method, as she had done in the spontaneous manipulation phase. The other child, a 24-month-old male, also never performed a reversal. He repeatedly placed cup 5 on the top of the stack and removed it again, without reversing it to the bottom. He succeeded only after he set cup 5 aside on the table and then moved the stack into it.

Elicitation trial B was expected to be difficult for the young children in this study, and it was: only four children achieved full seriation of the set of six cups, and none of them did so with no errors. As in the other trials, seriation was correlated with age, $r_{ph} = 0.41$, $df = 38$, $p < .01$, with one 36-month-old male and three 42-month-old female seriators. All four of these children had achieved full seriation on both of the preceding trials. Seriation on elicitation trial B was related to seriation on the spontaneous trial ($\phi = 0.39$, $df = 38$, $p < .01$) and elicitation trial A ($\phi = 0.37$, $df = 38$, $p < .01$).

The situation at the beginning of elicitation trial B called for the insert correction strategy. The number of subjects who used insert again increased with age (0, 0, 1, 6, and 6 subjects in the five age groups), $r_{ph} = 0.50$, $df = 38$, $p < .001$, although no one solved the trial in the minimum number of moves by removing the cups just to the point where the extra cup should go, putting that cup in its correct position, and replacing the removed cups in their correct order. There was consistency across trials in the use of insert: Ten of the 13 subjects who evidenced insert on elicitation trial B had also performed at least one insert during the spontaneous manipulation trial (two of the remaining three had achieved errorless seriation in that phase). The reversal correction strategy was again significantly correlated with age, $r_{ph} = 0.47$, $df = 38$, $p < .01$. 
Discussion

With little or no prompting, children between 1½ and 3½ years of age attempted to order a set of five nesting cups by size. As expected from previous findings (Greenfield et al., 1972; Sugarman, 1983), they used increasingly complex methods (composition procedures) to combine the cups. At every age, however, they also committed numerous errors in the process of manipulating the cups, and they spontaneously attempted to correct the majority of these errors. Our main purpose was to examine the error correction process and to look for developmental progress in this important but understudied form of self-regulation (Brown & DeLoache, 1978; Wilkinson, 1982).

The procedures the children used in their attempted corrections changed substantially with age, becoming increasingly more flexible and involving more extensive restructuring of the relations among the cups. The strategies that involved no or only minimal reordering of the relations among the cups (Force, Decompose, Try an Alternative) were all negatively related to age. With the most primitive strategy, Force, the children's effort was concentrated solely on a single, misplaced cup. With Decompose, although the children seemed to know something was wrong, they failed to generate an alternative ordering to what they had just done. With Try an Alternative, the children recognized that something was wrong with the way in which the cups were arranged, but their diagnosis of the problem was only one relation deep: Only two cups, and only one way of relating them, were considered at a time.

In contrast, the three strategies based on reordering the cups (Rearrange, Insert, Reverse) were all positively correlated with age. Thus, the idea of reordering is not an automatic reaction to the detection of an error, but rather is itself related to age. Furthermore, the latest-appearing strategies involved not just the reordering of elements, but also the coordination of relations. Insert required simultaneously considering the relation of a given cup both to the next larger one and to the next smaller. With Reverse, the child destroyed a relation that he or she had just created between two cups, immediately creating a new relation between those same two cups. To do so, the child must in some sense have realized that the two cups could be related to each other in more than one way.

The ability to execute a reversal did not guarantee that its use would be adaptive. For example, some subjects performed double or even triple reversals on the same set of cups. One 36-month-old placed cup 4 on top of 1/2/3/5, reversed them to 1/2/3/5/4, and then proceeded to reverse the cups two more times, ending up with 1/2/3/5/4. In the very difficult elicitation trial B, one child reversed the same two cups fully five times. In cases such as these, reversal had degenerated into a procedure much like force: The child repeated a procedure that bypassed the real problem (which was in the ordering of the internal cups and not the two outside cups, the ones affected by a reversal). Still, the fact that even the maladaptive use of this procedure emerged late suggests that the idea of reversing the role of a given cup involved a complex level of conceptualization.

The developmental course of the correction strategies thus reveals a progression from a focus on (a) a single nonfitting cup, to (b) the relation between two cups, to (c) multiple relations involving either the same two cups or the same cup in relation to the two surrounding cups. This progression is captured in yet another way: older versus younger children's application of the most rudimentary strategy, Force. The 18-month-old children, none of whom ever performed a reversal, most often used force (49% of their force attempts) when pressing cup 5 on top of another cup or nest. The only direct way to remedy this situation (i.e., the only way other than disassembling the entire stack, which some children did) was to perform a reversal, switching cup 5 to the bottom. Lacking this means of solution, the younger children focused their corrective efforts on that single, nonfitting cup and tried to force it to fit. The older children most often resorted to force (52%) when a cup that they had placed on top of the nest would not go in, because an intervening cup was already in the base cup but was obscured by the top cup. When these children applied force, they were taking into account the relationship between the nonfitting top cup and the base cup. Their expectations were reasonable in the context of what they could see; however, they were neglecting the third, invisible but intervening cup. Thus, the youngest children resorted to force when focusing on one nonfitting cup that they had no ready means of integrating with the stack, whereas the older subjects used force when taking into account the relation between two cups.

The same, progressively deeper, analysis of the relations between the cups is also suggested by the use of increasingly flexible composition procedures (originally docu-
mented by Greenfield et al., 1972), which correlated with the correction strategies described here. The children became progressively less likely simply to collect together single cups, one at a time (pot method), and increasingly more likely to employ the more complex subassembly procedure. The older children were thus more capable of shifting from using a given cup in one role at one moment to using it in the opposite role in the very next moment. Given that the underlying structure of the Reverse (error-correction) and Subassembly (composition) procedures is strikingly close (in two immediately sequential manipulations, the same object changes from the insertable to the recipient role or vice versa), it is not surprising that these two procedures were highly correlated with each other.

The importance of these two highly flexible procedures was made especially salient by their absence from the behavior of some children. Rather than use subassembly to combine a correctly composed multicup unit with another cup or cups, some children took apart the correctly seriated construction and moved the constituent cups one at a time. For example, one 24-month-old had constructed two stacks, 1/2 and 3/4/5. Instead of simply moving the two-cup unit, 1/2, into 3/4/5 and thereby achieving full seriation, he removed 1 from 2, then moved cup 1 into 3/4/5 and finally placed 2 on top. Thus, to avoid moving two cups together, this child went from being one step away from full seriation to producing a disordered stack that he was unable to correct; he subsequently dumped all the cups out and gave up. An example of the problems encountered by a subject without the reversal strategy is provided by an 18-month-old who had nested cups 1/2/3/4, but then placed cup 5 on top of the stack. This misordered construction can be made completely correct in one move by moving cup 5 from the top to the bottom of the stack. Instead, this young child took 5 off, put it back on again, pressed on it, took it off, and quit.

In the present research we observed considerable developmental progress in error correction—how children attempt to correct their errors in ordering the nesting cups—but not in error detection. Even the youngest children in our study generally recognized when they had committed an error. However, in other research on error detection and correction, both processes have been found to develop (Wilkinson, 1982). Our results are probably due to at least two interrelated factors. For one thing, as we have emphasized before, the nesting cups provided unambiguous and immediate feedback to the children as to the correctness of their response. We have data with these same children showing that in other seriation tasks with less clear feedback, they did not show the same rate of error detection and correction. With stacking rings and graduated sticks, tasks in which the elements are ordered by size but will nevertheless fit together in incorrect orders, these children rarely corrected their disorderings.

Second, and related to the above, extensive error correction efforts, such as we observed in the present study, are probably likely to occur only when the errors prevent the child from attaining his or her own goals. With the nesting cups, even the 18-month-old children adopted as their own goal fitting the cups together. Errors in ordering the cups precluded attaining this objective. With the other seriation tasks, the child’s self-adopted goals may have differed from the experimenter’s definition of the situation. With the stacking rings, for example, our impression was that many of the children were simply attempting to get all the rings on the pole; they were not attempting to get them on in any particular order. Since “errors” in ordering the rings did not prevent the child from achieving this goal, those “errors” were ignored. Thus, whether children will detect and attempt to correct their own errors depends on the extent to which the task informs them that they have erred, as well as the extent to which the error interferes with their objectives.

What is the generality of the developmental course we have documented in young children’s strategies for correcting their errors in manipulating a set of nesting cups? The increased scope and flexibility of the strategies have parallels in other realms of cognitive development. For example, the development toward a coordination of different ways of relating things has recently been shown for other object-ordering problems. Evidence from spatial classification tasks and children’s production of simple one-to-one correspondence constructions suggests that by 2½ or 3 years of age, children begin to coordinate the between-object relations they construct (Sugerman, 1982, 1983). They demonstrate an awareness that any given object could be related to another object (or to other objects) in any one of several ways. Thus, in both classification and correspondence tasks, and in the most advanced correction (Insert, Reverse) and composition (subassembly) strategies we observed, young children become in-
increasingly able to treat a given object as at once (or in rapid succession) the focal point of two different relations.

Direct parallels of the error correction process that we observed in the present research can also be found. One comes from a study of memory-based searching (DeLoache & Brown, 1984) in which developmental progress was observed in very young children's ability to restructure a situation and reorganize their behavior in the face of failure. Younger toddlers tended to search for a missing toy in places where they had found it in the past (i.e., they repeated previous responses), whereas slightly older 2-year-olds seemed to infer likely new locations for the missing object and reorganized their searching accordingly. The two age groups thus differed in their ability to conceive of alternative courses of action when what they had just done was not successful, just as the children in the present study became increasingly likely to change the order of the cups after an error. In future investigations of the error correction process, we plan to examine microgenetic changes in young children's manipulation of nesting cups, and we also plan to look for parallels in how children correct the errors they make in other domains (e.g., inserting shapes into a form box).

We note, finally, that the early reversibility in conceptual structuring that we have documented seems to fall largely outside the treatment of similar problems by Piaget (e.g., Inhelder & Piaget, 1964), the major theorist in the area. As we already noted, Piaget used quite different materials to study such problems as seriation. Sticks were used, rather than objects such as cups that afford functional feedback. It is not merely the solubility of the problem that is affected by this feature. There is more behavior for the observer to see and from which to make inferences about why the children are maneuvering the particular pieces they are into the positions they do. The inferences we have made have been about the judgments our subjects are making step by step to manipulate the materials as they do. Although Piaget's inferences also have to do with thought processes (mental operations), his inferences are based on what for us would pass as product data, and they characterize a generally more reflective level of thinking than we are after (see Sugarman, 1982, for elaboration). Thus, the present findings provide evidence for a line of development that Piaget did not emphasize, not evidence for an operation delineated by Piaget that one might expect to have emerged later. Precisely because these process analyses provide evidence for previously uncharted developments, they are important to pursue (see Karmiloff-Smith & Inhelder, 1975, and Thornton, 1982, for an analogous argument involving older children).

In summary, the results of the present study clearly demonstrate that consideration of the process of error correction can supplement and extend substantially one's understanding of the cognitive structures underlying children's problem-solving efforts. Our examination of correction strategies revealed important developmental trends of increasing flexibility and expanding scope of thought and action: The children became increasingly able to undo an unsuccessful action and institute an alternative approach, and they became increasingly able to coordinate multiple relations rather than focusing on a single object or relation. The improvement with age in the rate of seriation was due more to the older children's greater success at correcting their own errors than to any heightened ability or tendency to avoid errors. Investigations of the development of problem solving should take into account not simply the development of positive procedures for approaching a desired goal, but also procedures for getting the problem solver back on the track after being derailed by his or her own mistakes.

References


