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Development of Analogical Problem-Solving Skill

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HOLYOAK, KEITH J.; JUNN, ELLEN N.; and BILLMAN, DORRIT O. *Development of Analogical Problem-Solving Skill*. *CHILD DEVELOPMENT*, 1984, 55, 2042–2055. 3 experiments were performed to assess children's ability to solve a problem by analogy to a superficially dissimilar situation. Preschoolers and fifth and sixth graders were asked to solve a problem that allowed multiple solutions. Some subjects were first read a story that included an analogous problem and its solution. When the mapping between the relations involved in the corresponding solutions was relatively simple, and the corresponding instruments were perceptually and functionally similar, even preschoolers were able to use the analogy to derive a solution to the transfer problem (Experiment 1). Furthermore, salient similarity of the instruments was neither sufficient (Experiment 2) nor necessary (Experiment 3) for success by preschool subjects. When the story analog mapped well onto the transfer problem, 4-year-olds were often able to generate a solution that required transformation of an object with little perceptual or semantic similarity to the instrument used in the base analog (Experiment 3). The older children used analogies in a manner qualitatively similar to that observed in comparable studies with adults (Experiment 1), whereas the younger children exhibited different limitations.

Analogical thinking is widely recognized as a hallmark of human intelligence, and as such the course of its development is a topic of clear importance. The developmental literature in this area has almost exclusively concerned itself with “analogy problems” of the sort used in intelligence tests, most commonly “proportional” analogies of the form A:B:C:? (for a brief review, see Sternberg, 1982). The consensus of most of this research is that children have great difficulty solving even simple analogy problems prior to at least age 9 (Levinson & Carpenter, 1974; Lunzer, 1965; Piaget, Montangero, & Billeter, 1977; Sternberg & Rifkin, 1979). Experimental studies of the development of metaphorical comprehension indicate that performance is generally poor prior to middle childhood (Winner, Rosenstiel, & Gardner, 1976), unless the

metaphor is based on salient perceptual similarities (Vosniadou & Ortony, 1983).

However, some sensitivity to analogical relations is apparently within the competence of very young children. The essence of analogical thinking is the transfer of knowledge from one situation to another by a process of mapping—finding a partial set of correspondences between the elements (objects, attributes and relations) that form the mental representations of the two situations (Hesse, 1966). Mapping processes seem to underlie both social modeling (Holyoak & Gordon, 1984) and “make-believe” play, which are clearly exhibited by 3-year-olds (Garvey, 1977). For example, when a girl pretends to be the mother of her doll, she modulates her behavior to bring it into correspondence with

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that of an appropriate adult, while making the doll "behave" like an infant. Gentner (1977) demonstrated that 4-year-olds could respond appropriately when they were shown a picture of a mountain and asked such questions as, "If the mountain had a knee, where would it be?" (i.e., the children preserved relative spatial positions when mapping human body parts onto the picture). Gentner's task seems very similar to pretend play. Young children's success in her study may reflect the simplicity of the higher-order relation between the mapped relations, which was typically identity on such perceptual dimensions as relative height.

Understanding analogical thinking requires more naturalistic experimental paradigms than the proportional format that has typically been employed. While a great deal of work has been done on the solving of analogy problems, relatively little has been done on the *use* of analogy in solving problems, by children or adults. Yet in everyday life a primary function of analogical thinking is not to "solve analogies" (unless one is taking an intelligence test) but rather to help solve novel problems by relating them to known situations, which may sometimes be drawn from very different semantic domains. Analogies in science (e.g., the analogy between the motion of billiard balls and of gas particles) involve the use of one situation as a framework for constructing a causal model of another (Oppenheimer, 1956).

Recent studies have begun to investigate the processes by which adults solve problems by analogy. A paradigm that has been used to study analogical problem solving by college students involves having subjects solve a problem after reading a story describing an analogous problem and its solution (Gick & Holyoak, 1980, 1983). For example, Gick and Holyoak (1980) had subjects attempt to solve Duncker's (1945) "radiation problem" after reading about an analogous military problem. The radiation problem allows a variety of potential solution plans. By varying the solution to the military problem provided in the story analog, Gick and Holyoak were able selectively to facilitate discovery of particular solutions to the radiation problem. While most subjects were clearly able to solve the radiation problem by analogy, many failed to notice the relevance of the story until given a hint to use it. In addition, lessening the degree of correspondence between the two problem situations reduced the frequency with which subjects produced the analogous solution.

The present study adapted the paradigm developed by Gick and Holyoak (1980, 1983)

to investigate the development of analogical problem-solving skill. Our aims in the three experiments reported below were twofold. First, we wished to determine at what age children are first able to apply simple analogies to perform a goal-directed problem-solving task. The earlier the age of success, the more likely it is that analogy provides a potential mechanism for early cognitive development. Second, we sought to answer more analytic questions concerning the conditions under which young children succeed or fail in using analogies and the components of analogy use that pose particular difficulty. The latter aspect of the study was guided by Holyoak's (1984) analysis of the components required to solve a problem by analogy. These are (1) constructing mental representations of a known analog (the base) and of the novel analogous problem (the target), (2) noticing the potential analogy between the base and target, (3) constructing an initial partial mapping between the elements of the base and the target, and (4) extending the mapping to construct a solution procedure appropriate for the target problem.

Experiment 1

Experiment 1 was designed to assess the abilities of children at two different age levels to use analogies to solve problems.

Method

Transfer problem.—The transfer problem used in this study, the "ball problem," was adapted from the "pea problem" discussed by Raaheim (1974). Two bowls were set on a table, one within the child's reach and one farther away. One bowl contained a number of small gumballs, and the other was empty. Also on the table were an aluminum walking cane, a large rectangular sheet of heavy paper (posterboard), a hollow cardboard tube long enough to reach the farther bowl, child-safe scissors, string, tape, paper clips, and rubber bands. The subjects' task was to devise as many ways as possible, using the materials provided, of transferring the balls from the filled to the empty bowl without leaving their seat. Like the radiation problem used with adults by Gick and Holyoak (1980), the ball problem allows multiple solutions, making it possible to facilitate alternative solutions selectively by varying the prior analog. However, the ball problem is less complex and requires motoric rather than verbal solutions, making it more suitable for use with young children.

Story analogs.—Two stories were used as base analogs. Each was a picture-book fairy

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tale, written and illustrated by the second author. The text of the two stories is provided in the Appendix. The beginning of each story was the same and concerned a genie who wished to move his home from one bottle to another. The genie faced the problem of safely transferring a number of precious jewels to the new bottle. The two stories described different solutions used by the genie. In the "magic staff" story the genie used his magic staff to pull the new bottle over to the side of the old one. In the "magic carpet" story he commanded his magic carpet to roll itself into a tube, placed it so as to form a "hollow bridge" between the two bottles, and then rolled his jewels through it. Each story was accompanied by a series of colored pictures illustrating the story. Each step in the solution was clearly depicted.

Analogical correspondences.—Table 1 presents a schematic outline of the major analogical correspondences between the two stories and the ball problem, including the main analogous solutions to the latter. Each problem and solution is organized in terms of an abstract "problem schema," consisting of an initial state, solution plan, and outcome. The representation in Table 1 is an abstraction that omits the various noncorrespondences between the story analogs and the ball problem (e.g., the genie has magical powers whereas the child does not; the child has available items such as scissors that do not map onto objects in the story).

To use these analogies the genie can be mapped with the child, the jewels with balls, the bottles with bowls, and (depending on which story is provided) the magic staff with

the cane or else the magic carpet with the sheet of paper. The relations involving the above objects (e.g., transferring) can also be mapped. These correspondences can be used to construct a solution to the ball problem. The solution suggested by the magic staff story is to use the cane to draw one bowl closer to the other; that suggested by the magic carpet story is to roll the sheet of paper to form a tube, position the tube between the two bowls, and then roll the balls through the tube. Accordingly, successful use of a story analog should be evidenced by an increase in the frequency with which the analogous solution to the transfer problem is generated by subjects.

The materials provided with the ball problem afford a second solution that is partially analogous to the magic carpet story; the balls can simply be rolled down the cardboard tube. This tube solution is a somewhat less complete analogy than is the rolled paper solution, since it does not involve construction of a tube. But for this very reason the tube solution requires a less detailed mapping; it can be viewed as a "shortcut" procedure based on a mapping with the later stages of the genie's solution. In addition, the cardboard tube probably appears more similar to the carpet rolled into a tube than does the sheet of paper to the flat carpet. The tube solution should therefore be easier to produce than the rolled paper solution, given the magic carpet analog.

Procedure.—Each child was tested individually in a session lasting 10–20 min. In the magic staff and magic carpet conditions, the experimenter first read the appropriate story

TABLE 1

SCHEMATIC OUTLINE OF BALL PROBLEM SHOWING CORRESPONDENCES WITH ANALOGOUS STORIES

| | Story Analogs | Ball Problem |
|-----------------------|--|---|
| Initial state: | | |
| Goal | Genie wishes to transfer jewels from one bottle to another. | Child wishes to transfer balls from one bowl to another. |
| Resources | Magic staff/magic carpet. | Walking cane/sheet of paper. |
| Constraint | Must not drop or lose jewels. | Must not drop or lose any balls. |
| Solution plan 1 . . . | Genie (a) uses magic staff to pull goal bottle closer to initial bottle; (b) drops jewels into goal bottle. | Child (a) uses cane to pull goal bowl closer to initial bowl; (b) drops balls into goal bowl. |
| Solution plan 2 . . . | Genie (a) rolls magic carpet to form a long hollow tube; (b) places tube so it extends from initial bottle to goal bottle; (c) rolls jewels through tube to goal bottle. | Child (a) rolls sheet of paper to form long hollow tube; (b) places tube so it extends from initial bowl to goal bowl; (c) rolls balls through tube to goal bowl. |
| Outcome | Jewels are transferred safely. | Balls are transferred safely. |

to the child, pointing to the accompanying pictures. To ensure that the children understood the story, they were asked to retell it to the experimenter, who questioned them about any major aspects that they omitted. Some of the younger children required an explanation of what a "genie" was, but all subjects appeared to understand the story by the end of the initial part of the session.

Subjects in the two story conditions then were presented with the ball problem; those in the control condition were given the ball problem without any prior story. The child was seated next to the filled bowl and asked to remain in the chair, so as not to be able to simply reach to the empty bowl. The problem was introduced as a game involving moving the balls from the nearer to the farther bowl, using any of the materials on the table. The experimenter pointed to each of the objects individually, but did not name them. Subjects were encouraged to manipulate the available objects freely and to produce as many possible solutions as they could. To separate children's ability to notice the analogy from their ability to apply it, those in the story conditions were not immediately told that the story was related to the problem. However, if they appeared to run out of ideas without producing the analogous solution, the experimenter gave two progressively more specific hints: "Does anything in the story help?" and "What did the genie do and could you do anything like that?" If the child produced an analogous solution, the experimenter asked how the child arrived at it. The experimenter recorded all solution attempts in order of occurrence, noted the timing of hints, and recorded pertinent comments by the subject. The session lasted until the child appeared to be unable to come up with any further possible solutions.

Subjects.—Forty-eight subjects were tested, divided into two age groups, with approximately equal proportions of boys and girls within each age level and experimental condition. The younger group consisted of preschool children in nursery schools and a kindergarten, ranging in age from 4-7 to 6-0, with a median age of 5-6. The older subjects were fifth and sixth graders, ranging in age from 10-0 to 12-0, with a median of 11-0. The 30 preschool subjects were divided equally among the two story conditions and the control condition. Of the 18 older subjects, 10 served in the magic carpet condition and eight in the control condition. The magic staff story was not used with the older subjects after it became apparent that performance by youn-

ger subjects in that condition was near the ceiling.

The procedure was also piloted with several children still younger in age (3-2 to 4-4). Since it proved difficult to ensure that these subjects understood the stories and transfer problem, the attempt to use such young children was terminated.

Results and Discussion

Frequencies of analogous solutions.—The major results concern the frequencies with which the three critical solutions—use of the cane, rolled paper, and the cardboard tube—were produced by subjects in the various conditions. These frequencies are presented in Table 2, broken down by solutions given before and after the first hint to consider the story. All the solutions reported in Table 2 were executed successfully. Since subjects were asked to give multiple solutions, some subjects produced more than one of the target solutions. All significance levels reported in this paper for differences in solution frequencies are based on Fisher's exact probability test.

The preschoolers were clearly able to derive the cane solution to the ball problem by applying the magic staff analog. All 10 of the subjects who were given the magic staff story produced the cane solution, as opposed to only one subject in each of the other two conditions, $p < .001$ for each comparison. Five of the magic staff subjects gave the cane solution without any hints to use the story. There was also evidence that the magic staff analog created a "set" effect, in that the frequency of the nonanalogous tube solution was reduced relative to the control condition, $p < .05$. Gick and Holyoak (1980) found similar evidence indicating that story analogs can decrease the frequency with which adult subjects produce nonanalogous solutions.

The magic carpet story, on the other hand, had a much less clear effect on solution frequencies for the preschool subjects. Three subjects produced the analogous rolled paper solution when given the story (all without hints), as opposed to just one subject in the control condition and none in the magic staff condition. This difference, while suggestive, involved frequencies too small to merit statistical comparisons. Nine of the 10 magic carpet subjects generated the partially analogous solution, use of the tube; however, this may not have reflected use of the analogy, since eight of the 10 control subjects produced the same solution without any prior analog.

TABLE 2
 NUMBER OF SUBJECTS SUCCESSFULLY PRODUCING CRITICAL SOLUTIONS TO BALL PROBLEM
 AS A FUNCTION OF AGE AND STORY CONDITION, EXPERIMENT 1

| GRADE AND CONDITION | TYPE OF SOLUTION | | | | | | | | | |
|-----------------------|------------------|-----------|-------|--------------|-----------|-------|----------|-----------|-------|-------|
| | Cane | | | Rolled Paper | | | Tube | | | Total |
| | Pre-hint | Post-hint | Total | Pre-hint | Post-hint | Total | Pre-hint | Post-hint | Total | |
| Preschool: | | | | | | | | | | |
| Control (N = 10) | ... | ... | 1 | ... | ... | 1 | ... | ... | ... | 8 |
| Magic staff (N = 10) | 5 | 5 | 10 | 0 | 0 | 0 | 3 | 0 | 3 | 3 |
| Magic carpet (N = 10) | 1 | 0 | 1 | 3 | 0 | 3 | 7 | 2 | 9 | 9 |
| Grades 5 and 6: | | | | | | | | | | |
| Control (N = 8) | ... | ... | 0 | ... | ... | 0 | ... | ... | ... | 0 |
| Magic carpet (N = 10) | 0 | 1 | 1 | 3 | 7 | 10 | 9 | 1 | 10 | 10 |

NOTE.—Hints to use stories were only given in the story conditions, not in control conditions.

It is possible that discovery of the tube solution may have tended to block generation of the rolled paper solution by subjects in the magic carpet condition; for this reason, the tube was not presented to subjects in Experiments 2 and 3. In addition, there are several reasons to view the analogy with the magic staff story as simpler than that with the magic carpet story. The staff and cane share more perceptual and functional attributes than do the magic carpet and sheet of paper, which should facilitate the mapping process in the former case. In addition, the latter solution involves the construction of a more elaborate sequence of mappings between relations (first forming the tube, then positioning it, then rolling the balls through). The difficulty of arriving at the rolled paper solution may also be increased by the fact that the solution procedure in the story analog allows a less than complete mapping (the genie forms a tube by a simple command, whereas the child must actually roll the paper and decide how to keep it rolled, perhaps by using a rubber band).

In contrast to the younger subjects, those in the older age group were clearly able to generate solutions on the basis of the analogy between the magic carpet story and the ball problem. All 10 of the subjects given the story produced both the rolled paper and tube solutions, whereas none of the control subjects produced either, $p < .001$ for both comparisons. Eight subjects in the story condition gave the tube solution immediately as their first solution, and nine gave it prior to a hint to use the story. The rolled paper solution appeared more difficult, as all but three children required a hint before they generated it. The frequency of the latter solution for the magic carpet condition increased significantly across the two age groups, $p < .001$. In addition, four of the story subjects at the older age level also tried to turn the hollow aluminum cane into a tube by removing the stoppers from its ends, a solution none of the control subjects attempted. These subjects thus gave evidence of having used the story analog and transfer problem to induce a general "schema" for various types of tube solutions. (See Gick & Holyoak [1983] for discussion of the relationship between analogical thinking and schema induction.) In general, the older age group had difficulty in noticing a potentially useful analogy, but not in applying it, as has been observed in comparable experiments with adults (Gick & Holyoak, 1980, 1983).

One surprising feature of the results was the apparent decrease in the frequency of the tube solution from the younger to the older

control group (eight out of 10 vs. zero out of eight subjects). We have no firm explanation for this trend. It may be that the younger children had had more recent experiences manipulating similar tubes in art classes or that the older children had developed competing associations that led to increased functional fixedness. Also, the older control subjects produced more total solution attempts (see below), some of which may have blocked generation of the tube solution. The older subjects did not simply ignore the tube, however, as four of the eight used it in some other way (three used it as a scoop and one as a blow-pipe).

Other solution attempts.—As would be expected given the variety of materials available, subjects made numerous types of solution attempts other than those related to the story analogs. Some of these were crude, such as throwing the balls; some were more creative, such as using the tape dispenser as a scoop; many were unduly optimistic, such as using a paper clip as a catapult. Total number of solution attempts (not counting repetitions of the same solution) did not differ significantly across conditions within either age level. The number increased substantially (means of 2.95 vs. 5.00) from the younger to the older age level, $F(1,36) = 12.4$, $p < .01$, for the two comparable conditions (control and magic carpet). A different pattern emerged when only *successful* solutions were scored. These included the solution types presented in Table 2 plus several others, such as rolling the ball across the unfolded paper to the bowl. For the younger subjects, the mean number of successful solutions was 1.70 for both story conditions and 1.30 for the control condition. These differences were not statistically significant. For the older subjects, the means were 2.20 for the magic carpet condition and .38 for the control condition, $F(1,18) = 45.3$, $p < .001$. The older control subjects thus tended to produce a large number of different solution attempts, but few that were actually successful—fewer, in fact, than the younger control subjects, $F(1,16) = 5.08$, $p < .05$. This difference reflects the fact that the older control subjects did not produce the tube solution, as noted above. In contrast, for the magic carpet condition the older age group produced significantly more successful solutions than did the younger group, $F(1,18) = 6.08$, $p < .05$, largely because of the greater success of the older group in generating the analogous rolled paper solution.

Process of applying analogies.—Subjects' spontaneous comments and responses to

questions were scrutinized for evidence regarding the process of analogical problem solving. All subjects in the magic carpet condition at the older age level were clearly aware that their analogous solutions had been suggested by the story; most seemed surprised that the experimenter needed to ask. Seven of the 10 magic staff subjects in the younger group indicated in some way that they noticed a relation between the story and the target problem, as did two of the three successful magic carpet subjects. Many subjects at both age levels exhibited behavioral signs of excitement and triumph after generating an analogous solution.

A few of the younger subjects made spontaneous comments that revealed details of the mapping process. Several children referred to the bowls on the table as "bottles," suggesting a mapping with the prior story. One child in the magic carpet condition said he produced the tube solution "Cause I saw the genie roll his towel." Two subjects in the magic staff condition referred to the cane as a "magical cane"; and another exclaimed, "Just like the genie!" after producing the cane solution.

Perhaps the most revealing protocol was obtained from one of the very young pilot subjects, a girl aged 4-4 who was given the magic carpet story. After being introduced to the transfer problem, she immediately picked up the cardboard tube and rolled the balls down, saying, "Let's pretend they're real jewels." Later in the session she said, "That will be a magic carpet," and then laughed as she picked up the paper, rolled it, and asked the experimenter to help tape it. "That's the way the genie did it," she cried as she rolled the ball through the newly constructed tube. "I did it just like the genie." Here the process of analogical mapping is transparently revealed.

Two instances of control subjects drawing analogies to extraexperimental situations were noted. One preschooler began the problem by exclaiming, "I know!" and then giving the tube solution and no others. When asked why she solved the problem this way, the girl replied, "Cause I always do that. I use marbles at home." A sixth grader, the only subject to use the tube as a blowpipe, said she got the idea because "It's sort of . . . like a peashooter." These observations are consistent with the possibility that children also use analogies to solve problems outside of the laboratory situation.

Experiment 2

The results of Experiment 1 indicate that 11-year-olds can use an analogy between

superficially dissimilar problems to derive a solution to a transfer problem in a manner qualitatively similar to adult performance. This skill is less developed in preschoolers. Experiments 2 and 3 were designed to provide a more detailed assessment of the factors that influence the success or failure of younger children in using analogies.

The strongest evidence from Experiment 1 that preschoolers have some degree of skill in solving problems by analogy came from the magic staff condition, in which all subjects produced the analogous cane solution. It may be objected, however, that this positive result was critically dependent on the salient perceptual and functional similarity between the staff illustrated in the story analog and the cane available to solve the target problem. Perhaps the young children did not attend to the detailed correspondences between the base analog and the target but rather followed a simple strategy of using an object with salient similarities to the instrument in the story. Experiment 2 tested this possibility by comparing the effectiveness of the magic staff story used in Experiment 1 with that of other versions in which the analogical correspondences with the ball problem were less complete, even though the staff was used in exactly the same way. If young children follow a simple strategy of using an object functionally and/or perceptually similar to the instrument depicted in the prior story, they should generate the cane solution with equal frequency across all story conditions. However, if the children are in fact mapping relations between the base and target, the stories with reduced correspondences will lead to fewer cane solutions. Gick and Holyoak (1980) found that adult subjects are sensitive to variations in the degree of analogical correspondence between a story analog and target problem.

Method

Story analogs.—Three illustrated stories were used as base analogs: the original magic staff story used in Experiment 1 and two new versions (see Appendix). All of the stories involved a genie who used his magic staff to pull a new bottle up next to his old one and then dropped jewels from the old bottle into the new one. Thus all the stories contained elements that can be mapped onto the cane solution to the ball problem. However, the two new versions differed from the original story in that they introduced changes that lessened the degree of analogical correspondence with the transfer problem. In the extra-character version, a friend of the genie is introduced into the story. Although the basic

plot is identical to that of the original version, the friend is an element of the base analog that does not map onto the subsequent transfer problem. The altered-goal version also introduces the friend as an additional character, but in addition the primary goal of the genie is changed. The genie is now trying to move into a new bottle big enough to share with his friend; the transfer of jewels is treated in a relatively incidental manner. Accordingly, the altered-goal version is less analogous to the ball problem than either of the other stories.

Design and procedure.—Subjects served in one of three conditions, receiving either the original version of the magic staff story, the extra-character version, or the altered-goal version. The transfer problem was identical to the ball problem as it was presented in Experiment 1, except that the tube was not among the objects available to the child, whereas a coffee scoop and a long dowel with a slit at one end were included. The procedure was identical to that of the story conditions in Experiment 1, except that a more prolonged hint sequence was used if the child failed to produce the cane solution in response to even the second hint (i.e., “What did the genie do?”). The second hint was repeated several times using slightly different wordings (e.g., “Could you do what the genie did?”) before the session was terminated. No control group was run because the opposing hypotheses being tested depend solely on differences in solution frequencies among the story conditions.

Subjects.—Eighteen kindergartners and first graders, with approximately equal proportions of boys and girls across conditions, served as subjects. They ranged in age from 5-4 to 7-2, with a median age of 6-4, and thus were approximately 1 year older than the preschoolers used in Experiment 1. Eight subjects received the original version, and five received each of the other two versions.

Results and Discussion

All children were able to repeat the gist of the story to the experimenter and mentioned the use of the cane to move the bottle and transfer the jewels. Comprehension appeared equally good for all three versions. All

subjects who received one of the two new versions mentioned the genie’s friend in retelling the story, indicating that they attended to that aspect of the story.

The result of central interest involves the frequency of the cane solution across the three conditions. As the data in Table 3 indicate, all eight children in the original condition generated the cane solution, compared with only one of five subjects in each of the other conditions. The difference in solution frequencies between the original condition and the other two combined (100% vs. 20%) was highly significant, $p = .001$.

The striking decrement in performance associated with the two new versions (especially the extra-character version, which involved only a relatively small change in the completeness of the mapping) clearly indicates that the cane solution does not result simply from task demands or leading prompts from the experimenter. Protocols for these conditions indicated that subjects often failed to generate the cane solution despite a great deal of problem-solving effort and extensive hints from the experimenter. With respect to effort, the mean number of total solution attempts (including repetitions) was almost twice as large for subjects who received the new versions than for those who received the original (5.13 for the original version, 10.40 for the extra-character version, and 11.40 for the altered-goal version). The difference between the original condition and the other two was significant, $F(1,16) = 7.81, p < .02$, indicating that subjects in the latter conditions expended more overall effort. The same pattern was apparent when mean number of nonredundant attempts was compared (means of 5.13, 7.40, and 9.00 for the original, extra-character, and altered-goal conditions, respectively). No subjects in Experiment 2 produced successful solutions other than the cane solution (e.g., none produced the rolled paper solution).

In an attempt to determine just how difficult it might be to elicit the cane solution with a weak analogy, the session for one subject in the altered-goal condition was extended. This subject failed to generate the

TABLE 3
NUMBER OF SUBJECTS PRODUCING CANE SOLUTION, EXPERIMENT 2

| Story Version | Pre-hint | Post-hint | Total |
|-----------------------------|----------|-----------|-------|
| Original ($N = 8$) | 1 | 7 | 8 |
| Extra-character ($N = 5$) | 0 | 1 | 1 |
| Altered-goal ($N = 5$) | 0 | 1 | 1 |

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cane solution by the conclusion of the standard procedure. Further prompts were then given in an extended session lasting a total of 35 min. The subject eventually generated the cane solution, but only after it was virtually "given away" by the experimenter. The subject noticed the cane at the very beginning of the problem-solving session, mapped elements of the story with elements of the target problem, was led to consider the general idea of moving a bowl, and even the idea of using a hook, yet still did not generate the cane solution. The solution was finally given only after extensive prompting and a total of 18 prior solution attempts.

The results of Experiment 2 clearly indicate that perceptual and functional similarity between objects in the base and target analogs is not by itself sufficient to elicit the analogous solution reliably. Rather, young children are sensitive to the degree of correspondence of multiple components. Preschoolers' skills are fragile and easily disrupted. Mismatch of goals or protagonists impairs performance despite perceptual and functional similarity of objects. Furthermore, children typically require hints to consider the prior problem.

Experiment 3

Experiment 3 tested whether children could use a story analog to derive the more complex rolled paper solution. The results of Experiment 2 indicate that perceptual and functional similarity of elements is not a sufficient condition for analogical transfer, but they do not exclude its necessity. Whereas Experiment 2 was designed to find conditions under which it is relatively difficult to generate the cane solution by analogy, Experiment 3 was designed to find conditions in which it is possible for young children to generate the rolled paper solution. Several aspects of the procedure were altered to investigate this more complex solution, which involves less similarity between story and solution.

In Experiment 1 the magic carpet story did not clearly elicit a significant number of rolled paper solutions among the preschool subjects. At most, subjects mapped from the constructed tube in the story to the constructed tube on the table. In Experiment 3 a constructed tube was not presented. New versions of the story were written, one involving rolling a carpet and the other a blanket. The perceptual similarities between magic staff and cane and between constructed tube in the story and tube in the task (Experiment 1) seem much greater than between a blanket or a carpet on the floor and the sheet of paper on

the table. The standard functions of carpet and blanket are clearly different from a piece of paper. Of course, in an analogy between two tasks involving the manipulation of concrete objects, there must be some similarity among objects, such as "rollability," for the solution in one to be relevant to the other.

Slightly younger subjects were used in Experiment 3 than in Experiment 1, but several additional changes were introduced to facilitate discovery of the target solution. New story analogs were written involving characters more familiar to the subjects than genies. In addition, some subjects received two story analogs rather than just one, a manipulation that facilitates transfer for adult subjects (Gick and Holyoak, 1983). The tube was not included among the objects the child could use, to ensure that its availability did not block generation of the rolled paper solution.

Method

Story analogs.—Two new stories were written and illustrated (see Appendix), based on characters from the Peanuts cartoon strip and the Muppets television program. In "Woodstock's Eggs," Snoopy rolls up a blanket and uses it to transfer eggs to a nest. In "Miss Piggy's Jewels," Miss Piggy rolls up a carpet and uses it to transfer jewels to a safe. Neither story contains elements with salient perceptual or functional similarities to those required for the analogous solution to the ball problem (i.e., rolling a piece of paper into a tube to transfer gumballs).

Design and procedure.—Subjects served in one of three conditions. Those in the one-analog condition received one of the two story analogs prior to the transfer problem; those in the two-analog condition received both stories; and those in the control condition attempted to solve the ball problem without any prior story. Within the one-analog condition each of the two stories was used equally often; and within the two-analog condition each order of the two stories was used equally often.

The story or stories were read to subjects in the same manner as in the previous experiments. After each story, subjects were asked to retell it. Children in the two-analog condition were not told that the two stories were related to each other. The transfer problem was then administered. No constructed tube was provided, but a new "obvious" solution was added. The coffee scoop and dowel used in Experiment 2 were hooked together to make a long-handled scoop that could be used to transfer the gumballs. This "obvious" potential solution was intended to ensure that

subjects did not become discouraged by failure to find any successful solution.

Subjects.—Twenty-four subjects, ranging in age from 4;1 to 5;0, served as subjects. Twelve subjects were assigned to the control condition, and six were assigned to each of the other two conditions.

Results and Discussion

As in the previous experiments, all subjects appeared to comprehend the stories readily. Table 4 presents the number of subjects in each of the conditions who generated the rolled paper solution either before or after a hint to use the story. The results clearly indicate that the preschoolers used the story analogs to construct the critical solution. Overall, seven of the 12 subjects who received analogs (either one or two) produced the rolled paper solution, as contrasted with zero of the 12 control subjects. Fisher’s exact probability test showed the number of critical solutions to be significantly higher for the analog conditions than the control condition, $p = .002$ for total solutions, $p < .05$ for solutions prior to any hint. The fact that the advantage of the analog conditions was significant even for pre-hint solutions is evidence against the possibility that the result simply resulted from more extensive prompting of subjects in the analog conditions than those in the control condition. The frequencies involved in the one-analog and two-analog conditions were too small to yield statistically significant differences between them.

Although the story analogs were clearly effective in eliciting the rolled paper solution, performance was less than perfect. The subjects who failed to produce the critical solution did so despite prompting to use the story and to “do the same thing as Snoopy/Miss Piggy.” One child responded to the suggestion, “Could the story help?” by retrieving two pictures that had been used to illustrate the story and using them to push the balls around. Another child repeated that Miss Piggy rolled up the carpet to make a tube, but denied that he could do anything like that.

Another responded to prompts by saying he could roll a blanket up, but that there was no blanket on the table. Such protocols suggest that the preschoolers sometimes had difficulty performing the mappings required to use a story analog when the corresponding elements lacked obvious perceptual and functional similarities.

The total number of successful solutions, which mainly consisted of use of the long-handled scoop in addition to rolling of the paper, also tended to be higher for the analog groups than for the control group (means of 1.42 and .75 solutions per subject, respectively), although the difference fell short of significance, $F(1,22) = 3.06, p = .09$.

General Discussion

This study has implications for the development of analogical reasoning skills and for the potential contribution of analogical reasoning to other aspects of development. The study demonstrates that even preschoolers can use analogies to solve problems. It also begins to diagnose when children are likely to succeed or fail in using analogies and how the factors limiting successful performance change with age.

For 11-year-olds, the factor limiting performance on our simple problem seems to be the same as for adults solving more complex problems (Gick & Holyoak, 1980, 1983). Like adults, our subjects frequently failed to notice that two situations might be analogous. Once the analogy was pointed out, the 11-year-old subjects were uniformly able to carry out the necessary mapping much as adults do.

The situation is not so simple with younger children. The 4–6-year-olds did demonstrate considerable ability in analogical problem solving. However, their ability is more fragile, varies more from child to child, and is limited by different factors. The results of Experiment 1 suggest that preschoolers are able to solve a problem by analogy if the mapping between the relations involved in the corre-

TABLE 4
NUMBER OF SUBJECTS PRODUCING ROLLED PAPER SOLUTION, EXPERIMENT 3

| Condition | Pre-hint | Post-hint | Total |
|-------------------------|----------|-----------|-------|
| Control ($N = 12$) | ... | ... | 0 |
| One analog ($N = 6$) | 1 | 2 | 3 |
| Two analogs ($N = 6$) | 3 | 1 | 4 |

NOTE.—Hints to use stories were only given in the story conditions, not in control condition.

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sponding solutions is relatively simple and the corresponding instruments are perceptually and functionally similar (the magic staff condition). Experiment 2 demonstrated that such similarity of instruments is not a sufficient condition for success; rather, young children are extremely sensitive to the completeness of the overall mapping between the base and target analogs. The difficulties young children encounter in using analogies are therefore not attributable to their use of a simple strategy of using an object with salient similarities to the instrument depicted in the prior story.

Experiment 3 demonstrated that a high degree of perceptual and functional similarity is not a *necessary* condition for analogical transfer, even for children as young as 4 years old. When the story analogs mapped well onto the target problem, these young subjects were often able to generate the rolled paper solution. This solution requires a relatively complex mapping involving the transformation of an object (paper) that has relatively little perceptual or semantic similarity to the instruments used in the base analog (either a blanket or a carpet). Taken together, the experiments demonstrate that children as young as 4 years old can solve a problem by analogy to a superficially dissimilar problem and that a high degree of perceptual and functional similarity of the corresponding instruments is neither a necessary nor a sufficient condition for success (although it may well be helpful).

The performance of the young children, unlike the 11-year-old subjects, was highly variable. Some 4-year-olds spontaneously noticed and elaborated the set of mappings in the most difficult problem. At the other extreme was the child who responded to repeated prompts to "see if the story could help" by fetching the cards that had been used to illustrate the story and using them to push the balls. There are many possible sources for such variability in performance. Children differ in their familiarity with meeting the task demands of arbitrary adult-set goals. They differ in their experience with the story characters used in the base analogs and with the object-oriented "engineering" play required by the transfer problem. More research is required to determine which of the various possible factors are most critical.

Although young children did not always notice the analogy spontaneously, this did not seem to be the component that most severely restricted their performance. When prompted to use the story, many children could retell it,

mentioning the important elements. However, some rejected the idea that the story could be related to the problem. Others made a partial mapping (from jewels to balls, for example), but were unable to progress further. Such failures might be based on memory limitations that prevented children from simultaneously attending to and coordinating the components of the analogs. Alternatively, the differences between the contexts of the story-reading task and the ball-transfer game may have made the mapping seem implausible.

With age the limitations on successful analogical problem solving seem to shift from the mapping processes to the decision processes involved in initiating an attempt at mapping. This represents a change from development of "tactical" context-dependent skills (e.g., the ability to perform a mapping) to development of "strategic" skills related to the circumstances for appropriate application. Similar shifts from learning local skills to learning appropriate contexts of use are found in many other aspects of cognitive development, such as number skills (Gelman & Gallistel, 1978) and communication skills (Shatz, 1978).

The use of somewhat open-ended tasks and interview procedures provides a sensitive method for discovering children's abilities. However, when using a procedure responsive to a complex set of the child's activities rather than a simple criterion, the effects of variation in procedure are hard to assess. One concern is whether experimenter bias might have preferentially guided children to the "desired" solution, via unintentional cues. The magnitude of any such effect cannot be assessed from our data, but one finding argues against its importance. In Experiment 2, more solutions were attempted in the two altered conditions than in the original conditions, even though more analogous solutions were produced in the latter condition. The greater number of solutions elicited in the altered conditions might have reflected a bias of the experimenter to keep trying to evoke solutions when the target solution was not achieved, but argues against any simple account of experimenter attention evoking the "desired" response.

Our results indicate that under optimal circumstances children as young as 4 years old can make substantial use of analogies to solve problems. Analogical problem solving may in fact provide a basic mechanism for cognitive development. Analogy use allows the goal-directed transfer of information from a domain that is well understood to a novel domain that is not yet understood. Furthermore, there is

evidence that analogical mapping between two concrete problems fosters the construction of a more abstract knowledge structure that describes the commonalities between the two domains (Gick & Holyoak, 1983). This new knowledge structure facilitates subsequent transfer of knowledge to additional novel domains. The overall process of detecting analogies, finding mappings, and constructing new knowledge structures would yield "skill hierarchies" similar to those postulated in Fischer's (1980) theory of cognitive development. Our results generally support the possibility that analogical transfer is a potential mechanism for developmental change for preschoolers. The results have important implications for educational practice, suggesting that children are ready to benefit potentially from the use of analogy as an instructional device by the time they enter school. However, teachers need to be aware of the kinds of noticing and mapping difficulties that young children are especially likely to encounter.

Appendix

Story Analogs

Two Story Analogs to the Ball Problem Used in Experiment 1

Beginning—both stories.—Once upon a time there lived a magical genie. He was a very old, wise, and rich genie indeed. One day while he was polishing his home, which was actually a bottle, he decided he would like to find an even bigger and better home to live in. So he began searching far and wide for another bottle. Finally he found the perfect home. It was larger, prettier, and not too far away from his old bottle. The genie was very excited and began moving his belongings right away. But now the genie had a problem. He had a great many beautiful and very precious jewels in his old home. He had to somehow get all the jewels from his old bottle to the new bottle without dropping or losing a single jewel. After thinking a bit, the genie came up with a wonderful idea.

Continuation—magic staff story.—He began searching for his magic staff, or wand. He then commanded his staff to stretch itself from his old home to his new home. Next, the genie tugged and pulled on his magical staff until at last he pulled the new bottle right up next to his old bottle. At once, the genie began gathering his jewels together in his old home and simply dropped them carefully into his new home right next to him. When all his jewels were safely tucked away in his new home, the genie settled in happily. In fact, I'm sure you can still find him sitting in his new, bigger, and better bottle with all his jewels and smiling contentedly even today!

Continuation—magic carpet story.—He searched for his magic carpet. Then he commanded

it to roll itself up into a long hollow tube. Next the genie commanded his flying carpet to place one end at his old home and the other end at his new home so that it formed a sort of hollow bridge between the two bottles. Then, the genie very carefully took one jewel from inside his old home and placed it into the opening of his carpet. At once, the jewel began tumbling and rolling through the carpet tube until it reached his new home and plopped safely inside. The genie grinned happily and began rolling all his jewels through the carpet into his new home. In fact, I'm sure you can still find him sitting in his new, bigger and better bottle with all his jewels and smiling contentedly even today!

Two Additional Versions of the "Staff" Story Used in Experiment 2

Extra-character version.—Once upon a time there lived a magical genie. He was a very old, wise, and rich genie indeed. One day while he was polishing his home, which was actually a bottle, an old friend came up. The genie told his friend, "I'm going to look for a bigger and better home to live in. Will you help me look?" So they began searching far and wide for another bottle. Finally the genie found the perfect home. It was larger, prettier, and not too far away from his old bottle. The genie was very excited and wanted to begin moving his belongings right away. But now the genie had a problem. He had a great many beautiful and very precious jewels in his old home. He had to somehow get all the jewels from his old bottle to the new bottle without dropping or losing a single jewel.

After thinking a bit, the genie came up with a wonderful idea. He began searching for his magic staff, or wand. He then commanded his staff to stretch itself from his old home to his new home. Next, the genie tugged and pulled on his magical staff until at last he pulled the new bottle right up next to his old bottle. At once, the genie began gathering his jewels together in his old home and simply dropped them carefully into his new home right next to him. When all his jewels were safely tucked away in his new home, the genie settled in happily. He invited his friend to come in and admire his new home. His friend came in and said, "What a good house for you!" I'm sure you can still find the genie sitting in his new bigger and better bottle with all his jewels and smiling contentedly even today!

Altered-goal version.—Once upon a time there lived a magical genie. He was a very old, wise, and rich genie indeed. One day while he was polishing his home, which was actually a bottle, an old friend came up. The genie and his friend had lived together long ago. They talked about how much fun it had been to play and do magic together. The genie's friend said, "I'm looking for a new home right now." The genie said, "Let's find a bottle big enough for both of us. Then we can live together and have fun again." They began searching far and wide for a bigger bottle. They searched and they searched. Finally they found the perfect home, a bottle that was big enough for both of them. The genie was very excited. He wanted to move all his belongings right away so he and his friend could

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settle in. But the bottle was very far away and the genie had many beautiful jewels to move. It would be a lot easier for the genie to move if his new home was closer to his old one. Now the genie had a problem. How could he get his new bottle up close to his old bottle?

After thinking a bit the genie came up with a wonderful idea. He began searching for his magic staff, or wand. He then commanded his staff to stretch itself from his old home to their new home. Next, the genie tugged and pulled on his magical staff until at last he pulled the new bottle right up next to his old bottle. Then the genie was happy. He could move in no time at all. He gathered up his jewels in his old home and dropped them carefully into their new home right next to him.

Then the genie said to his friend, "What a wonderful home! Now we can play and do magic together every day." The genie's friend just smiled and smiled. I'm sure you can still find the two of them sitting in their bigger bottle playing and doing magic even today!

Two Story Analogs Used in Experiment 3

Woodstock's eggs.—Woodstock had built a nest on top of Snoopy's doghouse. She had put her eggs in it and was waiting for them to hatch and the baby birds to come out. But Snoopy was unhappy about all this. The nest was in the way when he tried to lie down. And Snoopy was afraid that when the baby birds arrived, they would make so much noise with their chirping that he wouldn't be able to sleep at all!

Woodstock didn't want to get Snoopy upset, and so she agreed that the eggs would have to be moved. So she built a new nest in a tree a little ways from Snoopy's house. But now there was one problem, and a very serious one. How would they move the eggs safely from Snoopy's rooftop to the new nest in the tree? Snoopy and Woodstock were both afraid that the eggs would get broken if they tried to carry them down from the roof and up the tree.

They both thought and thought. Then Snoopy had a great idea. While Woodstock hovered in the air watching, Snoopy took a blanket and rolled it up. Then he tossed it across so that it hooked on a branch of the tree. The rolled blanket stretched right across to the new nest. Then Snoopy carefully rolled the eggs one by one through the rolled blanket into the nest in the tree. All the eggs were soon moved safely. Woodstock liked her new tree nest, and Snoopy was finally able to sleep comfortably again on his rooftop.

Miss Piggy's jewels.—Miss Piggy's most precious possessions were her jewels. She kept them in a jewel box on top of her dresser. She decided they weren't very safe there, so she wanted to move them to a strong safe on the other side of the room. Miss Piggy started to carry a few of her jewels across the room to the safe. But just then Gonzo went running through the room, with Fozzy Bear chasing him. They almost knocked Miss Piggy down. She was afraid they would come back at any moment and make her drop some jewels and lose them. She

had so many jewels—how could she get them all over to the safe quickly and safely?

Suddenly Miss Piggy had a great idea. She rolled up her carpet off the floor and picked it up. The carpet just reached from her jewel box to the safe. Then Miss Piggy quickly rolled her jewels through the rolled carpet and into the safe. She was finished in a jiffy, before Fozzy Bear and Gonzo came back. The jewels were safe, and Miss Piggy was very happy.

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