REMOTE TRANSFER OF SCIENTIFIC REASONING- AND PROBLEM-SOLVING STRATEGIES IN CHILDREN

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I. Introduction: Theoretical, Empirical, and Practical Importance of Research in Remote Transfer

Transfer, the application of information acquired in original learning situations to new, relevant problems, is a fundamental and long-enduring issue in human cognition, children's learning, and education (e.g., Barnett & Ceci, 2002; Detterman & Sternberg, 1993; Singley & Anderson, 1989; Thorndike & Woodworth, 1901). The basic questions concern how, when, and how well people retrieve relevant information from long-term memory and use examples acquired in the past to solve analogous problems. Despite the unarguable centrality of learning and transfer in children's development, most studies in our field over the past decades "have focused on skills and knowledge at particular ages rather than on the processes through which children acquired the skills and knowledge" (Siegler, 2006). Consequently, the topic of transfer in children's learning and thinking has been rather peripheral in developmental psychology.

Among the tens of thousands of articles appearing in *Child Development, Developmental Psychology*, and the *Journal of Experimental Child Psychology* over the past half century, only about 1% address the topic of transfer, and even these few have been limited to studies focusing on the application of acquired information to fairly similar problem situations only after a short delay and within the same lab setting. Children's *remote* transfer—that is, the application of concepts and strategies across substantially different contexts and after a long delay—has been virtually unexplored. The domains or tasks in which children's transfer has been examined include memory strategies (Blöte *et al.*, 1999; Coyle & Bjorklund, 1997), mathematical reasoning (e.g., Alibali, 1999; Goldin-Meadow & Alibali, 2002; Rittle-Johnson, 2006; Siegler, 2002), number estimation (Siegler & Opfer, 2003), conservation (e.g., Gelman, 1969; Siegler, 1995), understanding of physical rules (Siegler & Chen, 1998), tool use and causal reasoning (Brown & Kane, 1990; Chen & Siegler, 2000; Chen, Sanchez, & Campbell, 1997), scientific-reasoning strategies (Klahr & Nigam, 2004; Kuhn, Schauble, & Garcia-Mila, 1992; Schauble, 1990, 1996), computer programming (Klahr & Carver, 1988), analogical mapping (Honomichl & Chen, 2006; Kotovsky & Gentner, 1996; Siegler & Svetina, 2002), transitive inference (e.g., Goswami, 1995), symbolic understanding (Chen, 2007; DeLoache, 2004; Loewenstein & Gentner, 2001; Marzolf & DeLoache, 1994), and theory of mind (Flynn, O'Malley, & Wood, 2004). The distance or gap in terms of context and time interval between the original learning and transfer tasks in these studies is quite narrow. Although this research on near transfer has provided critical insights into important aspects of children's thinking, we still know little about how broadly, flexibly, and effectively children transfer acquired strategies to remote situations, or about the processes involved in remote transfer.

But remote transfer, when it does occur, is a critical measure of children's learning, because it reflects how deeply children understand, how broadly they generalize acquired concepts and strategies to different situations, and how flexibly they think and reason. Thus, the examination of the processes involved in children's ability to transfer of strategies to distant situations should be a pivotal part of the research in children's thinking because it has theoretical, empirical, and practical implications.

With respect to theory, remote transfer studies provide critical tests for theories and models related to representation, learning, and intelligence. The process of remote transfer involves encoding information about the original learning situation, retrieving relevant information when encountering tasks that require similar strategies, establishing a mapping between the original and the new tasks, and applying the strategies to solve the current problems. The central questions are: (a) How do children embed source information in the original learning situations? (b) How do they represent information in a more general and flexible fashion? (c) How do they retrieve relevant information from long-term memory when encountering a novel problem? (d) How do they map the structures between problems despite differences in superficial features? and (e) How do they execute a solution in solving a target problem? Examination of children's remote transfer thus address key issues that are closely related to the nature of representations and the retrieval of source analogues, and to theories of human learning and cognition.

The empirical challenge, given the debates and mixed findings about the evidence of short-term transfer, is to demonstrate the existence of far transfer. Thus far, our knowledge of children's ability to transfer from original to remote and novel situations is only intuitive and speculative, and there is little empirical evidence that children retrieve and use acquired structural information or solution strategies to solve relevant problems in different contexts after a long delay.

Finally, there are practical educational implications that may be derived from an increased focus on far transfer, because the primary goal of education is to promote flexible and broad transfer of concepts or strategies to other contexts and situations (e.g., Halpern, 1998). Given the pivotal role of transfer in education, it is critical to explore the issues of how students learn and to what extent they apply what they learn, and to examine factors that facilitate broad and flexible generalization of knowledge across wide gaps. The issue bears upon the phenomenon of "inert" knowledge (Bransford *et al.*, 1986; Bransford *et al.*, 1989; Brown, 1989; Brown & Campione, 1981; Whitehead, 1929), defined as "knowledge that is accessed only in a restricted set of contexts even though it is applicable to a wide variety of domains'' (Bransford *et al*., 1989, p. 472).

The primary purpose of this chapter, therefore, is to demonstrate the extent to which children can demonstrate long-term transfer of higher-order cognitive skills over months and even years, and the ways in which such remote transfer depends on different acquisition conditions. In the following sections, we first discuss the paradox about the existence of remote transfer. The paucity of empirical studies on remote transfer might be a consequence of conceptual obstacles, or of methodological challenges, or both. We thus describe a conceptual taxonomy of transfer for measuring transfer distance. Then we present extensive new evidence of remote transfer in children. These studies were conducted using two promising methods: an experimental paradigm in which children learned a problem-solving strategy and then were given the opportunity to use that strategy in solving isomorphic problems after a long delay, and the naturalistic, a cross-cultural method in which children learned a problem-solving solution in various cultural settings and their problem-solving strategies were assessed in a laboratory context many years later. Studies with these two approaches yielded new insights about developmental differences in remote transfer and revealed key processes/components involved in remote transfer. We then address questions concerning the relation between the acquisition and the application of strategies, and finally we address the educational implications of these findings and suggest some future directions for research on children's remote transfer.

II. Paradox, Taxonomy, and Paradigms

The intensive research on near transfer over the past century has generated more questions than answers to key issues, and has presented in particular a paradox—dubbed by Dunbar (2001) as ''the analogical paradox''—between intuitive plausibility and empirical evidence of remote transfer. Human thinking and problem solving is unquestionably influenced by experience, and thus it would be quite implausible to suggest that prior knowledge plays no role in solving novel problems. Indeed, cognitive development would be impossible unless children were able to use what they learn at one point in time and in one context when encountering relevant tasks at another point in time and in another relevant context. However, significant transfer has proven difficult to demonstrate. The research in mostly short-term transfer over the past century has yielded conflicting findings, showing both transfer successes and failures, and leading to extensive debates about the existence of transfer. Although studies have demonstrated successful transfer even in young children (e.g., Brown & Kane, 1988; Brown, Kane, & Echols, 1986; Chen & Siegler, 2000), laboratory experimental results are often counterintuitive, showing that even older children and adults often do not make use of highly relevant information to which they are likely to have easy access. The narrowness of children's learning and a lack of transfer has been reported often (e.g., Bransford, Brown, & Cocking, 1999; Cognition and Technology Group at Vanderbilt, 1997; Lave, 1988), and consequently, the existence of transfer has been debated extensively, as evident in the book "*Transfer on Trial*" (Detterman & Sternberg, 1993).

The paucity of empirical studies of remote transfer is partially due to the fact that a clear conceptualization of the underlying construct of "transfer distance" remains elusive. Without an articulation of the dimensions of transfer, it is impossible to compare the different distances of transfer in a meaningful way. Barnett and Ceci (2002) formulated a taxonomy suggesting that transfer distance involves two taxonomic factors of transfer. The first general factor involves content, which includes the specificity–generality of the learned skills (e.g., transferring procedures or principles). The second factor involves context, which includes knowledge domain (e.g., biology vs. economics), physical context (school vs. lab), temporal context (time interval), functional context (e.g., academic vs. play), social context (individual vs. group), and modality (e.g., multiple choice vs. essay test).

We adapt Barnett and Ceci's taxonomy by separating "temporal context" from other aspects of context and combining content and knowledge domain. The three-dimensional transfer framework thus involves task similarity between the original source and target problems, context similarity between original learning and target problem solving, and time interval. The three key dimensions in defining transfer distance are as follows:

1. *Task similarity*: presence/absence of *shared superficial and structural features* between the source and target problems. The first dimension is whether the source and target tasks share structural similarity and overlap in superficial features. Superficial similarity refers to objects and their properties, story protagonists, story lines, format of the problems (e.g., verbal vs. hands-on manipulation), or task domain (e.g., mathematical, physics, or social domains) common to both problems, whereas structural similarity refers to the underlying relations among the key objects shared by the source and target problems (Gentner, Rattermann, & Forbus, 1993). Extensive research in children's analogical problem solving has shown that overlapped superficial features and shared common structures provide cues for

spontaneous retrieval of source information and mapping of structural relations between problems (e.g., Brown, 1989; Chen, 1996; Daehler & Chen, 1993; Gentner *et al.*, 1993; Goswami, 1996).

2. *Context similarity*: same/different *contexts* in which the solutions or strategies are acquired and used. The context in which the original or "source" task is acquired or a target problem is solved involves physical and/or social aspects. Physical context refers to the location where the source analogues are acquired and the target problems/tasks are encountered, whereas social context involves the people and activities associated with the target problems/task. Either of these two types of contextual similarities may provide cues for retrieval of the source information when encountering a relevant problem. In examining analogical transfer across context, Spencer and Weisberg (1986) showed that college students experienced difficulty in solving a target problem in a setting (laboratory or classroom) that was different from the context (classroom or laboratory) in which a source problem was learned, demonstrating the important role of contextual similarity in transfer. Still, only a few studies have addressed the issue of immediate physical/perceptual context in infants and young children's learning (e.g., DeLoache, 2004; Rovee-Collier, 1999), and we know little about the effects of this dimension on children's transfer of problem-solving strategies.
3. *Time interval*: short/long *time gap* between tasks, ranging from minutes to decades. Research on the development of memory reveals that, with an increasing time gap, it becomes increasingly challenging for infants, toddlers, and older children to recognize or recall the events to which they were exposed previously (e.g., Bauer, 1997; Ceci & Bruck, 1998; Rovee-Collier, 1999). However, despite the fact that the time gap between original learning and testing undoubtedly influences the retrievability and applicability of acquired information, this dimension has almost never been considered in investigating children's transfer.

Figure 1 depicts a three-dimensional transfer distance space. In this space, the circle at the left-bottom corner represents a source problem, and the cubes represent target problems that differ on different degrees in these three dimensions. Transfer distance between the source and target problems can thus be represented in different regions of the space. The distance between the source problem and Target Problem A depicts a typical relation between source and target problems, in which source and target differ somewhat in superficial task features, but are similar in context (e.g., the lab setting) with short-term delay. The relations between the source and

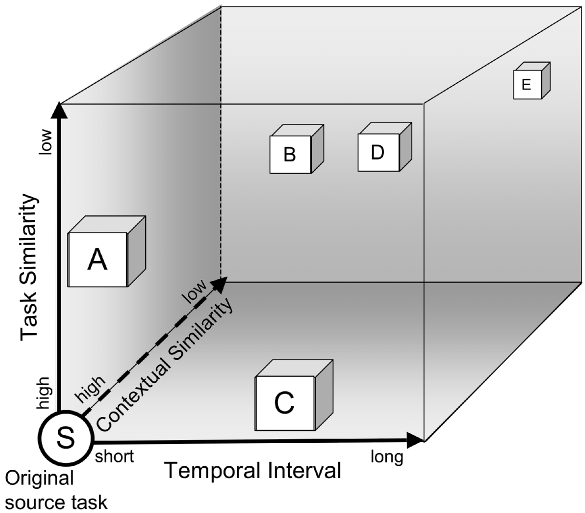


Fig. 1. A three-dimensional transfer distance space. The x*-axis corresponds to the* temporal interval *between the learning of the source task and the application of that knowledge to the target task. The* y*-axis corresponds to the* task similarity *between the source and target. The* z*-axis corresponds to the* contextual similarity *between the initial learning situation and the transfer situation. Each of the labeled cubes in the space corresponds to a different transfer distance between source and the target. Point A corresponds to the most common form of transfer assessment: high contextual similarity, medium task similarity, and a short temporal interval between training and transfer assessment, whereas point E represents a transfer task with a long time interval, and substantial differences between source and target tasks and contexts. The other points in the space are described in the text.*

other targets (Problems B, C, D, and E in Figure 1) represent the transfer distance in the remote transfer studies to be described in the following sections.

There is little doubt that the degree of transfer is (a) inversely proportional to the size of the temporal interval between the original learning experience and subsequent target problem solving and (b) directly proportional to the degree of semantic and contextual similarity between problems. However, theorizing and modeling in analogical problem solving have been almost entirely based on experimental results of short-term transfer within the same contexts. Previous research in transfer has typically manipulated levels of superficial similarity between learning and transfer problems while ignoring the last two dimensions. Results from such studies may thus exaggerate children's transfer ability, given that transfer distance is defined mainly only by the first dimension. Conversely, without considering contextual similarity and time delay, it is difficult to assess children's flexibility and effectiveness in using learned concepts and strategies.

As mentioned earlier, given the host of practical constraints involved in attempts to separate the presentation of source and target problems with a substantial time gap, most traditional studies of learning and transfer assess transfer performance within the same setting (i.e., laboratory context) and within a short interval. In this chapter, we describe studies in which we attempted to address these limitations by using two approaches to assess the transfer of problem-solving strategies after substantial delays and across distinct contexts. In one, an experimental approach, children acquired solutions or strategies in an original learning context, and their strategy use was then assessed using analogous tasks in different contexts with substantial time delays. This approach resembles the standard lab approach to studying transfer, except that it involves much longer durations between original learning and transfer assessment. Instead of delays of only a few hours or days, as in typical transfer studies, we assessed transfer many months after the initial acquisition of strategies and solutions and did so using a wide variety of test contexts.

In the second, naturalistic, cross-cultural approach, problem-solving strategies were assessed in a laboratory context, years after children acquired relevant solutions from stories, tales, and events in various naturalistic, cultural settings. This approach relies on naturally occurring differences between stories and events to which children in different cultures were exposed. More specifically, exposure to a culturally specific "source analogue" was presumed to be nearly universal and repetitive in one culture, but extremely rare in another. The comparison of children's performance in solving problems that are analogous to the specific experiences in one culture but not in another enabled us to examine remote transfer of analogous strategies acquired from specific cultural contexts. The use of this approach helps overcome the inherent obstacles in testing transfer across longer time gaps and contexts.

III. Evidence of Remote Transfer I: Experimental Approach

The experimental approach to examining remote transfer described in this chapter focuses on transfer of scientific-reasoning strategies (or processing skills) in children. Scientific reasoning involves basic inference processes in forming hypotheses, in designing experiments to test hypotheses, in distinguishing determinate from indeterminate evidence, and in interpreting results as evidence that support or refutes the hypotheses. Although children and even lay adults often have difficulty in engaging in scientific thinking, studies conducted since the 1990s indicate that—when given many repeated opportunities to reason about patterns of evidence—children and adults *are* capable of acquiring scientific processing skills (e.g., Klahr, 2000; Kuhn *et al.*, 1992; Kuhn *et al.*, 1995; Schauble, 1990, 1996). Most of these studies used a microgenetic approach in order to examine late elementary-school childrens' and adults' acquisition of scientific experimentation skills during many sessions spread over a period of 10 weeks or more.

Although these studies are significant for demonstrating scientific-reasoning strategies in both children and adults over an extended intervention period, they did not focus on the fundamental questions of whether and how younger children acquire and transfer scientific-reasoning strategies. Furthermore, the gap in time interval and contexts between the initial learning and transfer situations remained relatively narrow. A fundamental issue addressed in the studies described here concerns whether preschool and elementary-school children are capable of maintaining the strategies acquired in an initial learning situation and applying them to solve problems with long-term delays—of 7 months to 2 years—across contexts.

A. SEVEN- TO 10-YEAR-OLD CHILDREN'S LEARNING OF THE CONTROL OF VARIABLE STRATEGY IN DESIGNING EXPERIMENTS AND TRANSFERRING THE STRATEGY

Our first study (Chen & Klahr, 1999) addressed an important issue in scientific reasoning and cognitive development: how children learn a domain-general processing strategy of designing valid experiments—the control of variables strategy (CVS)—and generalize it across various tasks in different contexts. We define CVS in both logical and procedural terms. The logical aspects of CVS include the ability to make appropriate inferences from the outcomes of unconfounded experiments as well as an understanding of the inherent indeterminacy of confounded experiments. Procedurally, CVS is a method for creating experiments in which a single contrast is made between experimental conditions. The full strategy involves not only creating such contrasts, but also being able to distinguish between confounded and unconfounded experiments. Previous studies (Bullock & Ziegler, 1999; Kuhn, 1995; Kuhn *et al.*, 1995) indicated that elementary-school children had very limited understanding of CVS and demonstrated that the majority of fifth and sixth graders produced mainly confounded experimental designs.

Given that CVS is a fundamental scientific-reasoning skill and that few elementary-school children spontaneously use it when they should, it is important to identify effective ways to teach CVS. One aim of this study was to examine which approaches work best in facilitating children's acquisition of CVS, and to determine the extent to which children transfer CVS to situations beyond original learning context and after a long delay. For example, after learning how to design unconfounded experiments to determine various factors in the stretching of springs, are children able to utilize CVS in creating valid experiments dealing with balls rolling down ramps? Or do they apply the strategy only to situations that share very similar surface features?

This study consisted of two parts. Part I examined children's acquisition and relatively near transfer of CVS with the hands-on tasks. Part II was a paper-and-pencil posttest given several months after the initial learning phase. In Part I, with the hands-on tasks in each domain (task), children were asked to design experiments to test the possible effects of different variables. Several isomorphic, hand-on tasks were designed to help children master CVS. The tasks were physics based and involved springs, slopes, and sinking designs. In each task there were four variables that could assume either of two values. In each task, children were asked to focus on a single outcome that was affected by all four variables. For example, in the slope task (Figure 2), children had to generate test comparisons to determine how different variables affected the distance that balls traveled after rolling down a ramp. Children could set the steepness of the downhill ramps (either steep or low) using wooden blocks that fit under the ramps. Children could also set the surface of the ramps (either rough or smooth) by placing inserts on the downhill ramps either carpet-side up or smooth wood-side up and they could set determine how far the balls rolled on the downhill ramp by placing gates at either of two positions at different distances from the top of the ramp (long or short run). Finally, children could choose from two kinds of balls: either rubber squash balls or golf balls.

To set up a comparison, participants constructed two ramps, setting the steepness, surface, and length of run for each and then placing a ball behind the gate on each ramp. To execute a comparison, participants removed the gates and watched as the balls rolled down the ramps and came to a stop. The outcome measured was how far the balls traveled into the serrated stopping area. Figure 2 depicts a completely confounded comparison, as all four variables differ between the two ramps.

The key question in this study was whether, after learning how to design unconfounded experiments to determine the influence of various factors in the ball's rolling down ramps, children would be able to utilize CVS to create valid experiments dealing with different physical contexts, such as

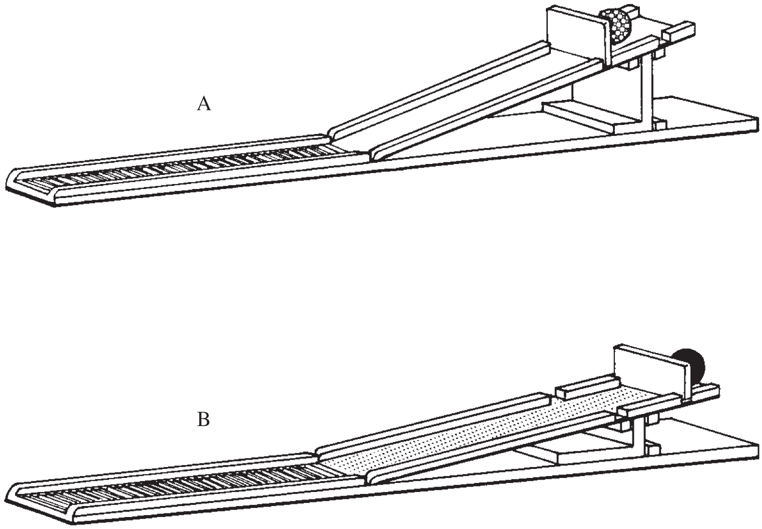


Fig. 2. The Slope Domain. On each of the two slopes, children can vary the angle of the slope, the surface of the ramp, the length of the ramp, and the type of ball to determine the effect of one of these four variables on how far a ball rolls along on the serrated stopping area at the end of the slope. The confounded experiment depicted here contrasts (a) a golf ball on a steep, smooth, short ramp with (b) a rubber ball on a shallow, rough, long ramp.

springs stretching or objects sinking in water. That is, would they transfer the underlying CVS procedure from one physical context to a very different physical context having the same deep structure or would they only apply the strategy to the contexts in which they were trained?

To test children's learning and transfer, in Part I children were assigned to different instructional conditions, which differed in whether children received explicit instruction in CVS and whether they received systematic probe questions concerning why they designed the tests as they did and what they learned from the tests. Children in the *training-probe* condition received explicit training instructions for the first comparison and were asked systematic probe questions about why they designed the test they did for each trial. Training included an explanation of the rationale behind controlling variables as well as examples of how to make unconfounded comparisons. After the test was executed, children were asked if they could "tell for sure" from the test whether the variable they were testing made a difference and also why they were sure or not sure. During training, the children were given both confounded and unconfounded examples and were asked to judge whether each example was a good or bad comparison and to explain why. The experimenter then provided rationales for why it was not a good comparison. In the *no training-probe* condition, children received no explicit training, but they did receive the same series of probe questions surrounding each comparison as were used in the training-probe condition. Children in the *no training–no probe* condition received neither training nor probes.

Using three isomorphic tasks, which shared the same structure but superficial features, children were asked to make a series of four paired comparisons to test particular variables of each problem in four phases of the study: Exploration (e.g., the Slope Task), Assessment (e.g., different variables of the Slope Task), Transfer-1 (e.g., the Sinking Task), and Transfer-2 (e.g., the Spring Task). (Note that each of these physical domains involves "hands-on" set up and execution of children's experimental designs.) The order of the tasks was counterbalanced. Children were presented with materials in a source task in which their initial CVS strategy was examined. Then their learning was assessed on the same initial task in the Assessment phase. This assessment measured children's *very near transfer*, defined as the application of CVS to test a new aspect (i.e., testing different variables) of the same materials used in the original learning problem. Children's performance on Transfer-1 and Transfer-2 phases, with one novel task on each phase, was measured to assess their *near transfer*, defined as the use of CVS to solve novel problems using a set of different materials that are still in the same general domain as the original problem within the same context after a short delay. This type of transfer resembles the traditional assessment of transfer, as Target Problem A illustrated in Figure 1. Children's *remote transfer* was examined in Part II. Remote transfer refers to the application of CVS to solve problems with domains, formats, and contexts different from the original training task after a long delay, as illustrated in the relation between the source and Target Problem B in Figure 1.

To determine whether and how children at different age levels and in different conditions change their strategies in designing experiments in Part I, the frequency of CVS use in each phase was examined. Children's performance in designing valid experiments in each phase is illustrated in Figure 3. The analyses indicated that only children in the training-probe condition increased their performance over phases: Training-probe children did better in the Assessment, Transfer-1, and Transfer-2 phases than in the Exploration phase. They increased the use of CVS from about one-third of the trials in the Exploration phase (before training) to nearly two-thirds of the trials at the end of the hands-on phase. In contrast, children's performance in the no training-probe and no training–no probe conditions did not significantly improve over phase.

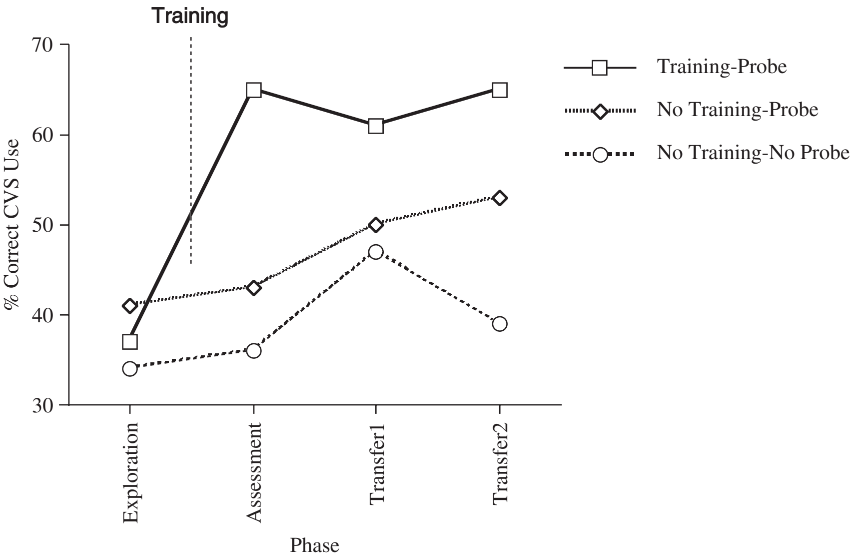


Fig. 3. *Children's initial learning and near transfer: percentage of trials with correct use of CVS by phase and condition. The between-subjects training treatment occurred between the Exploration phase and the Assessment phase. Each line represents the mean of 2nd, 3rd, and 4th graders.*

As Figure 4 illustrates, further analyses indicated that older children outperformed younger children and that children's performance patterns in different grades differed in each training condition. Only third and fourth graders in the training-probe condition improved their performance over phases. Second graders' performance improved somewhat between the Assessment and Exploration phases; however, their transfer performance was not better than the exploration performance. A similar pattern in age differences was also found in the no training-probe condition in that the third and fourth graders but not second graders showed some improvement over phases. Children in the no training–no probe participants showed no performance increases over phase for any grade level.

Elementary-school children thus demonstrated an impressive ability to apply learned strategies across problems in Part I. With appropriate instruction, elementary-school children are capable of understanding, learning, and generalizing the strategy when designing and evaluating simple tests. At the conclusion of Part I, all children received explicit training so that their remote transfer could be assessed at a later date. Given the scope of this chapter, we focus on children's remote transfer.

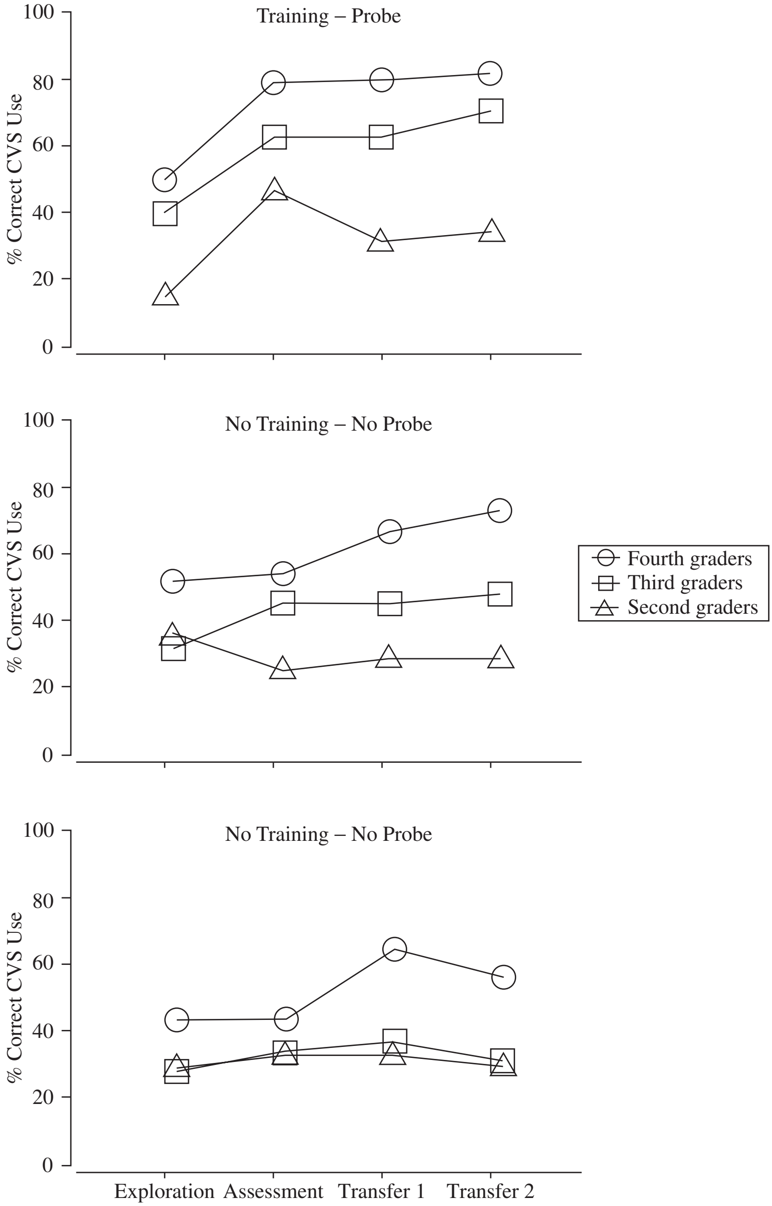


Fig. 4. Children's initial learning and near transfer by grade, phase, and condition: percentage of trials with correct use of CVS.

Part II was designed to examine children's ability to transfer CVS from the hands-on phases to remote situations after a 7-month delay. Third and fourth graders who had participated in Part I (except the second graders, who did not learn optimally in the earlier phases) and their classmates who had not previously participated were given a posttest in which they were asked to solve problems in various novel domains. The posttest tasks involved evaluating whether each of a series of paired comparisons was a good test of the effect of a specific variable (Figure 5). All children who had participated previously were considered the experimental group in the remote transfer test, while their classmates who had not participated made up the control group.

We consider the application of the general strategy, CVS, in the posttest as "remote transfer" for several reasons: (1) the tasks differed in several aspects, including the format (generating tests in the hands-on tasks vs. evaluating tests on paper in the posttest), content (mechanical vs. other types of domains; involving four variables vs. three variable of each problem); (2) the hands-on phase and posttest differed substantially in the testing context (working with an experimenter in the lab vs. their science

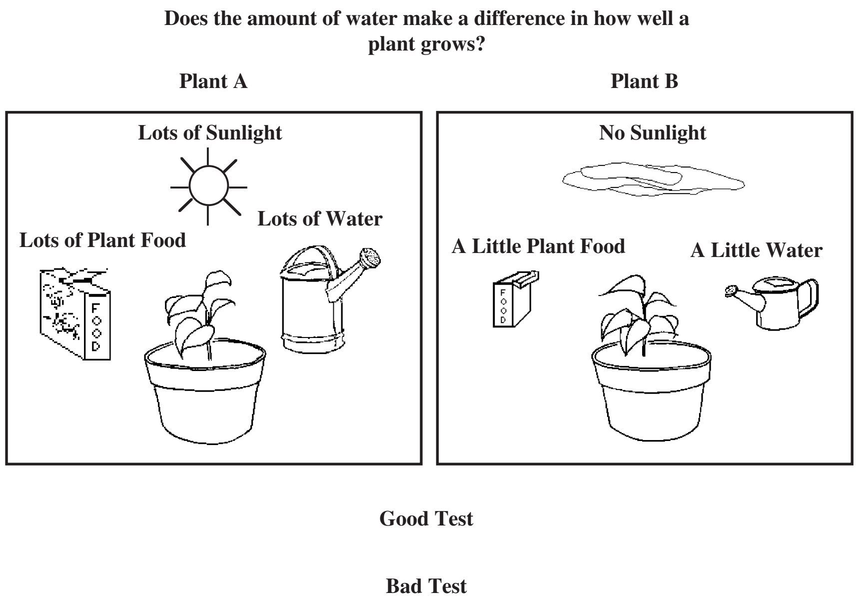


Fig. 5. An example of the CVS remote transfer task. The figure depicts one of the items in the 15-page test booklet. Children had to indicate whether they thought the depicted comparison was a "good test" or a "bad test" for the focal question. This example is a "bad test" because it is confounded.

teacher in the science classroom); and (3) 7 months elapsed between the hands-on experiences and the posttest. The difference between this posttest and the original learning represents a far region of the transfer distance space (Target Problem B in Figure 1).

The main dependent measure in Part II was the number of correct responses to the 15 posttest problems. Fourth graders in the experimental conditions outperformed those in the control condition, but conditions did not differ significantly for third graders. Another measure of remote transfer involved the percentage of "good reasoners" in the experimental and control conditions. Children who made 13 or more correct judgments out of a total of 15 problems (over 80% instead of 100% of correct strategy use to allow random errors) were considered good reasoners. As shown in Figure 6, 62% of children in the experimental group were categorized as good reasoners, compared to only 19% in the control group. Separate analyses at each grade level revealed that the experimental and control conditions differed in the percentage of good reasoners at grade 4, but not grade 3.

This study thus reveals developmental differences in learning and transfer of scientific-reasoning skills. Second graders, like older children, learned

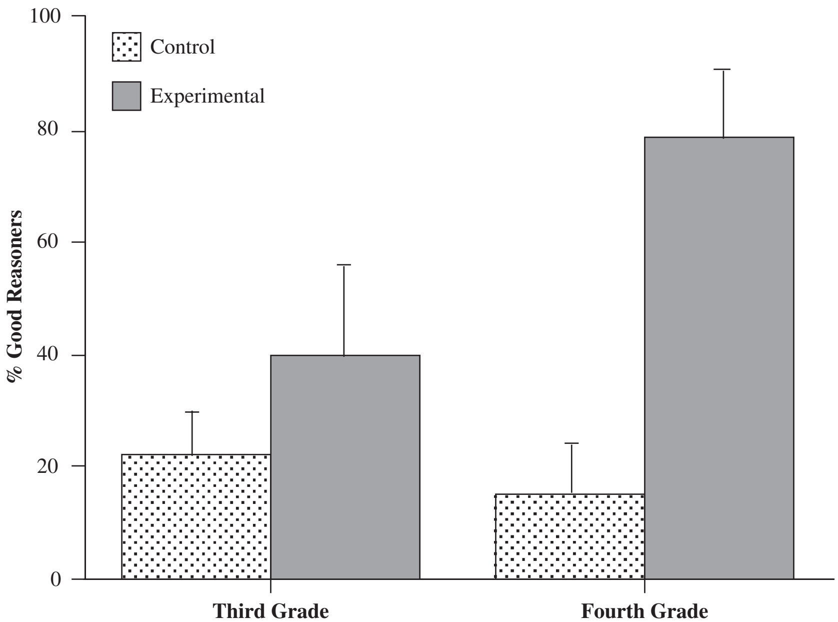


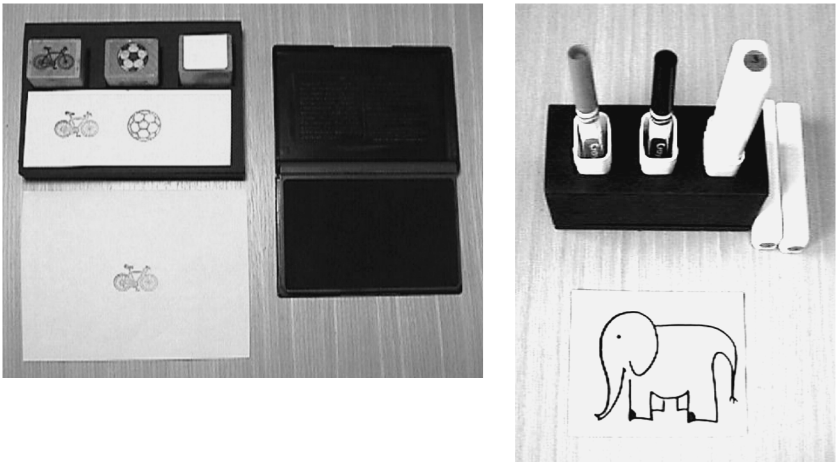
Fig. 6. Children's remote transfer performance: percentage of Good Reasoners (13 out of 15 correct) on the posttest administered after a 7-month delay.

CVS when the transfer tasks were within the same domain as the initial training. Third graders demonstrated the ability to transfer CVS across problems within the domain of mechanics (i.e., when reasoning about the springs, slopes, and sinking tasks) and with a short-term delay (one week). Only fourth graders displayed remote transfer. With age, children increasingly improve their ability to transfer learned strategies to remote situations; and children's transfer became increasingly flexible and broad.

B. FOUR- AND 5-YEAR-OLDS' UNDERSTANDING OF INDETERMINACY AND TRANSFER OF STRATEGIES AFTER A 7-MONTH DELAY

Children's ability to transfer learned strategies to remote situations undoubtedly is influenced by the complexity of the tasks that they face. Although second graders were ineffective in relatively near transfer (e.g., in transferring CVS from the Slope Task to the Spring Task) and third grader's performed poorly on a remote transfer task (from the original learning to posttest problems) perhaps even younger children could demonstrate transfer if given age-appropriate tasks. In a subsequent study (Klahr & Chen, 2003), we further examined remote transfer of scientific strategies in younger children. In this study, we focused on the time gap between the learning and transfer phases while minimizing the transfer differences between the tasks and contexts. The transfer distance is illustrated by point C in Figure 1: only the temporal interval between initial learning and posttest was substantial. We examined 4- and 5-year-olds' learning and transfer using an age-appropriate task involving children's assessment of the informativeness of different patterns of evidence.

The ability to distinguish determinate from indeterminate evidence is a prerequisite to appreciating the logic of evidence-theory relations and confounded vs. unconfounded experimental designs. We addressed the issue of children's acquisition and transfer of the concept of indeterminacy by presenting 4- and 5-year-olds with various isomorphic tasks (adapted from Fay & Klahr, 1996) as depicted in Figure 7. For example, in the marker task (Figure 7b), children saw a target object (e.g., a sketch of an animal) and a set of covered boxes each of which contained one marker. At the outset of each trial, all boxes were closed. Then they were opened sequentially, revealing the color of the marker contained in the box. Prior to the opening of each box, children were asked whether and why they "knew for sure," or "would have to guess," about which box contained the marker that was used to draw the animal. In the specific example shown in Figure 7b, the target is a sketch of an elephant drawn in black, and there are



(a) (b)

Fig. 7. Examples of materials used for determinacy/indeterminacy tasks: (a) "Stamps" problem. The task is to determine whether one can know for sure which stamp was used to make the bicycle image at the bottom. In Fig. 7a the identity of two of the stamps has been revealed: the first stamp (bicycle) matches the target and the second (soccer ball) does not, but the identity of the third stamp remains unknown because it is still hidden under the while tag. Thus, this is an example of a positive-capture problem. (b) "Marker" problem. The task is to determine whether one can know for sure which marker was used to make the sketch of the animal at the bottom. The identity (color) of two of the markers has been revealed: the leftmost marker is orange and does not match the color of the drawing (black) and the second one (black) does match, but the color of the third marker remains unknown because the marker cover has not yet been removed. Thus, this is also an example of a positive-capture problem.

three boxes, containing, respectively, orange, black, and black markers. We use the symbols "?," "+," and "-" to denote, respectively, a closed box, an open box that matches the target, and an open box that does not match. For the problem just described, the sequence of evidence patterns is as follows: before any of the boxes are opened: ???; after the first (leftmost) box, an orange, non-matching marker, is opened: -??; after the second box, containing a black, matching marker, is opened: -+?; and finally, after all boxes are opened: -++. This problem is indeterminate throughout. That is, there is never sufficient evidence to eliminate the uncertainty about which marker was used to draw the elephant. In contrast, although all problems start out with indeterminate evidence patterns, some become fully determinate after the final box is opened (e.g., -+-).

There was one evidence type for which only about 10% of 4-year-olds' and 15% of 5-year-olds' initial responses on the pretest were correct across conditions (Klahr & Chen, 2003). Such patterns included at least one closed box and a single positive instance (e.g., + - ?). On such problems, children incorrectly responded "know" approximately 80% of the time when they should have said "guess." Fay and Klahr (1996) called this the *positive-capture* strategy because the single positive instance seemed to capture children's attention and, in effect, blind them to the fact that the unexplored option might yet render the problem indeterminate. The positive-capture strategy resembles inclusion errors in scientific reasoning (e.g., Kuhn *et al.*, 1995), which involve attribution of causal relations to a variable that covaries with the outcome on only a single occasion. For example, in a task in which a set of manipulable features influence the speed with which boats are pulled down a towing tank by a weight and pulley system, children often make co-occurrence inclusion errors when they concluded that a feature (e.g., sail size) played a causal role in the speed based on a single instance (large sail co-occurred with fast speed), although there is no effect of this variable in the causal structure of the task. Younger children are particularly likely to generate this kind of error, but 11- and 14-year-olds and even adults often use incorrect single-instance inclusion inferences (Kuhn *et al.*, 1995). Thus, a form of the positive-capture strategy appears to cause difficulty in scientific reasoning well into adulthood.

Given the consequences of failing to recognize indeterminate situations in scientific reasoning, it is important to investigate whether and how, with experience, young children eventually replace it with a more advanced strategy. For investigating children's performance on a particularly difficult acquisition, we used a microgenetic training approach in which we provided explicit and systematic feedback on all pattern types over several days in several phases, including a pretest (e.g., the marker task on Day 1), two learning phases (e.g., the stamp task shown in Figure 7a for learning phases I & II on Day and Day 3), a posttest (e.g., an analogous task in which children were shown a necklace of colored beads as well as boxes containing one color of bead, and were asked to identify the box that was used to make the necklace), and a delayed transfer test, with 5 problems on each phase. The first four phases took place approximately a week apart, and the delayed transfer test took place 7 months later. Children were assigned to two learning conditions. In the learning phases, for the children in the training condition, correct and incorrect responses were pointed out, and the experimenter provided the rationale for the correct answer immediately after the child responded to each question. That is, children received immediate, explicit, and consistent feedback after each box was opened. In the control condition, children received no explicit feedback from the experimenter about whether their response was correct. Various isomorphic tasks with different materials were used to explore whether and how young children at different ages transfer the learned strategy from one task to another. The delayed transfer test took place approximately 7 months after the earlier learning phases. It was similar to the markers task described previously, except in the task presentation format, in that the experimenter and participants traveled throughout the room to pre-made pictures set on little tables in front of the marker boxes.

Not surprisingly, children at different ages responded differently to problem-solving experience in the control condition and the explicit feedback in the training condition. As Figure 8 shows, the analyses of learning on the positive-capture problems (a) children at both age and in both conditions started with similar inaccurate performance; (b) children in the training condition improved much more than their peers in the control condition; (c) 5-year-olds improved more than 4-year-olds throughout the learning phase; and (d) by the follow-up phase 7 months later, 4-year-olds' performance decreased almost to pretest levels whereas 5-year-olds' performance remained quite accurate. Developmental differences in strategy acquisition and generalization were therefore evident in several aspects: older children learned more readily from training, improved their performance to a greater extent, and transferred the learned correct strategy across tasks (e.g., from boxes to markers) more effectively, whereas for younger children the short-term effectiveness of training was not long lasting.

This study shows that although the positive-capture strategy is a robust phenomenon in young children's reasoning, 5-year-olds were able to learn from both problem-solving experience and especially from explicit feedback

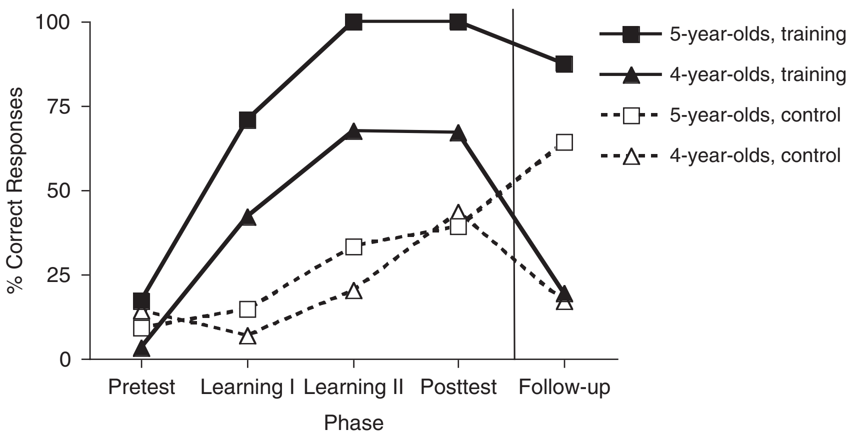


Fig. 8. Children's learning and transfer of correct strategies: percentage of correct responses to positive-capture problems over phase by condition and age. Learning I and II took place on Days 2 and 4, respectively. Posttest took place on Day 4, and Follow-up took place 7 months later.

but 4-year-olds' performance on indeterminacy problems benefited somewhat from explicit feedback but not from implicit feedback. Older children's learning proved more effective in magnitude, rate, and generalization. Although 5-year-olds were initially unable to process positive-capture problems, they learned readily from feedback to recognize and correctly explain both determinate and indeterminate situations, and the acquired strategy was effectively generalized across different tasks with a 7-month delay. Thus, compared to 4-year-olds, 5-year-olds improved their performance to a greater extent, learned faster, and generalized the newly acquired strategy to a broader range of indeterminacy tasks and to more remote situations.

In both the CVS and indeterminacy studies just described, the time gap between the initial learning and remote transfer phases, although substantially longer than the intervals reported in most previous studies with children and adults, was still relatively short (7 months). To further explore young children's remote transfer of scientific-reasoning strategies, we next examined young children's strategy transfer after a substantially longer time gap, in order to compare more directly children's shorter- and longer-term transfer.

C. SIX- TO 8-YEAR-OLDS' TRANSFER OF A HYPOTHESIS-TESTING STRATEGY AFTER A 24-MONTH DELAY

The ability to generate a conclusive test for a hypothesis is a critical component of scientific-reasoning processing (e.g., Klahr & Dunbar, 1988; Klayman & Ha, 1987). Early investigations of children's ability to understand hypotheses and evidence suggest that only by 11 or 12 years of age do children start to master the conceptual and procedural strategies required to seek and evaluate evidence that can either confirm or disconfirm hypotheses (e.g., Kuhn *et al.*, 1988). In contrast, some studies indicate that when presented with two relatively simple and mutually exclusive hypotheses, even early elementary-school children can correctly choose the "experiments" that conclusively determine which hypothesis is correct (e.g., Ruffman *et al.*, 1993; Sodian, Zaitchik, & Carey, 1991).

Sodian *et al.* (1991) told first and second graders a story in which they had to determine whether a big mouse or a small mouse was eating food in the kitchen each night. Children were told that they could place food in either of two houses: one with a big door that could accommodate either a large or small mouse, and one with a small door that could accommodate only a small mouse. Most children correctly reasoned that they should put the food in the house with the small door: if the food was gone in the morning, it must be a small mouse. Sodian *et al.* also demonstrated that children's responses were not simply due to a preference for the small house, because when the goal was changed from determining the size of the mouse to being sure that the mouse would be fed, they chose to use the house with the large door. In a second task, children needed to figure out how to determine whether a pet aardvark had a good or poor sense of smell. A good portion of children in both grades generated spontaneous tests (e.g., placing food far away) for a hypothesis, suggesting that they had some nascent understanding of the fundamental logic of hypothesis testing. However, young children's understanding of hypothesis testing involving choosing from two alternatives appeared very limited as shown in this study; only a little over a quarter of these children demonstrated the ability. Furthermore, the two tasks were presented one after another, and thus children might have learned from the experience after encountering the first task.

The Sodian *et al.* (1991) study provides an important "snapshot" of young children's hypotheses-testing strategies at a given point in time. In order to extend their findings, we focused on young children's acquisition and transfer of such hypothesis-testing strategies (Chen, Mo, & Klahr, 2006). Challenging tasks were designed to examine the ability of kindergartners and first and second graders to acquire and transfer the fundamental logic of hypothesis testing. The basic task involved designing an adequate test for a hypothesis by choosing a correct item from three options. For example, in one of the isomorphic problems, the "Who sank the boat?" task (Figure 9), children were presented a story in which a fisherman needed to figure out whether a big or small bear messed up his boats at night. The solution involved leaving one of his three different-sized boats in the water (the one that a big bear, but not a small bear, could sink). If it was sunk by morning, then the big bear must be responsible.

The general approach involved presenting three isomorphic tasks which involved testing hypotheses related to the size, weight, volume, or height of the target objects. Figure 9 illustrates an example of the "Who sank the boat?" problem (a weight task). The story was read to the child while the props were presented: "A fisherman has three boats of different sizes. One morning, he discovered some bear messed up his boats, but he did not know whether it was a small or big bear. He thought it might be a big bear, and thought of a way to figure out if it was a big or small bear by using his boats." In the first trial, the child was told: "Here are the three boats that the fisherman had. The fisherman knew that a big bear could sink all the boats (A, B, and C), but a small bear could sink only these two (B and C)." After confirming that the child understood and remembered the relations between the bear and the three boats, the child was asked to help the

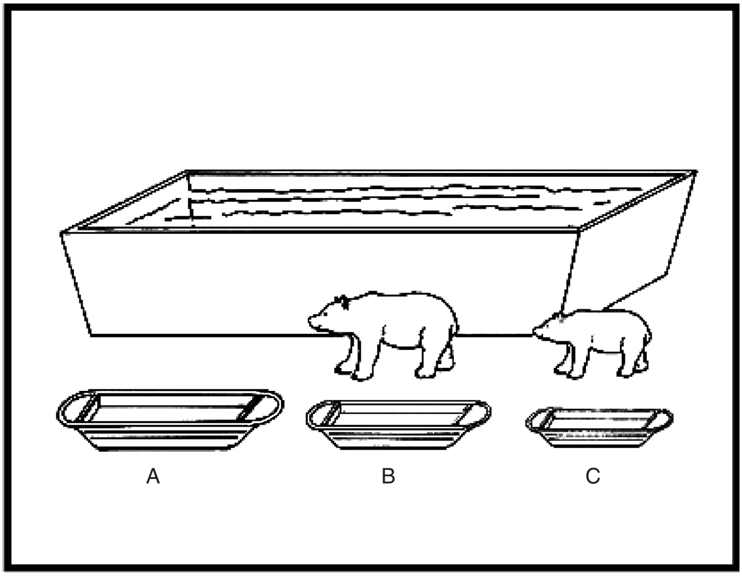


Fig. 9. An example of the hypothesis testing tasks: Illustration of the toy props used to accompany and illustrate the "who sank the boat" task (a weight task). The child was told that, for example, a big bear would sink all three boats, but a small bear could only sink the two smaller boats. Which size boat should be left out overnight to determine which of the two bears was the culprit?

fisherman figure out a way to test the hypothesis, and his/her strategies were assessed. The other three analogous tasks were an area task ("Who ate the food?" which was adapted from Sodian *et al*., 1991), a volume task ("Who spilt the water?"), and a height task ("Who took the gift?"). The height task was used during the posttest; the toy props used in this task are illustrated in Figure 10. The four tasks shared parallel problem structure and logic (all involving designing an adequate test for the hypothesis by selecting an appropriate item from alternatives based on the given relations between items and the target protagonist), but involved different objects, protagonist, and story line. The early task(s) served as analogue(s) for later one(s). Children's relatively near and remote transfer was assessed by comparing their initial performance, short-term transfer (learning within the initial phase), and remote transfer (12-month or 24-month-delay posttests).

To examine how various types of feedback affects remote transfer, a total of 110 kindergartners, first graders, and second graders from China were assigned to one of the three conditions distinguished by the type of feedback provided. On each of two trials for each task, depending on

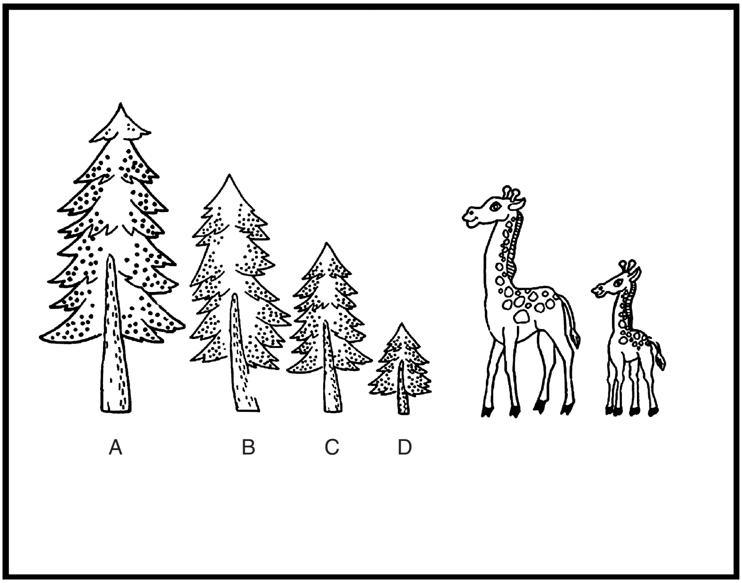


Fig. 10. Materials used for the posttest task: "who took the gift" (a height task). The child was told that, for example, the tall giraffe could remove a gift from any of the trees, but the small giraffe could only reach the two smaller trees. Where should the gift be placed?

different conditions, questions were asked and/or prop demonstrations were provided. These questions and demonstrations served as feedback as well as providing an assessment of children's strategies in solving the problems. The children at each age level were assigned to one of the three conditions. At the end of each trial, the children in the verbal and physical feedback (explicit) condition received verbal instruction and physical demonstration with props that a big, but not a small bear would sink a specific boat.

The verbal instruction illustrated how and why a correct choice would allow one to conclusively test the hypothesis: "If the fisherman chooses the biggest boat that the big bear could sink but the small bear could not, and if it was sunken by the morning, then he would be able to find out whether it was the big bear sank it. If he chooses a boat that both bears could sink, or a boat that either could sink, the fisherman would not be able to find out." In the physical feedback (intermediate) condition, only physical demonstration, but not verbal explanation was provided. Physical demonstration involved showing a correct choice and then an incorrect choice with the props and asking questions concerning why it was a good or bad choice. For example, in the case of a correct choice, the experimenter showed how an appropriate boat works: "Let's see what happens if the fisherman chooses this boat (Boat A). See, if the big bear steps on, the boat sinks. If the small bear steps on, it does not sink the boat. If the fisherman finds that the boat has been sunken in the morning, would he be able to tell whether it was the big bear that did so? And why?" In the implicit feedback condition, children received no explicit feedback, but the experimenter's very specific questions served as implicit feedback.

During the learning phase, children were tested individually with three analogous tasks, with two trials within each task. The trials within a task differed in the relations between the bear and boats. For example, on one trial, a big bear could sink the medium boat but not the big boat, and a small bear could only sink the small boat on the first trial. On another trial, a big bear could only sink the big boat, and a small bear could sink the medium and small boats. To ensure that children remember the relations, on each trial, after the relations were presented and before the inference questions were asked, the child was asked to remind the experimenter which boat (or box) a big bear (mouse) could sink (enter), and which boat a small bear could sink. In order to examine remote transfer, at the end of the learning and near transfer phase, all children were trained with the explicit instruction: the verbal and physical feedback at the end of the third (last) trial.

During the posttest—remote transfer one or two years later—only kindergartners and first graders participating in the verbal and physical and physical only conditions were tested in three trials of the posttest task. The posttest task is illustrated as point D in Figure 1, which represents a substantial distance between the initial learning phase and the posttest in task and context similarity, and in temporal interval (i.e., with a 12- or a 24-month time gap). Children in the implicit feedback condition, although ultimately receiving explicit feedback, did not learn to the same degree as those in the experimental conditions and thus were not included on the posttest. The posttest task would be less challenging when the second graders become fourth graders two years after they participated in the learning phase, and the second graders were thus not included on the posttests. A portion of the kindergartners and first graders participating in the two experimental conditions during the learning phase were tested one year later (first and second graders when the one-year-delay posttest was conducted). Classmates who never participated in the study served as a control group. Other kindergartners and first graders (second and third graders when the two-year-delay posttest was conducted) were tested 24 months later. Again, classmates who never participated in the study served as a control group. Neither verbal nor physical feedback was provided at the 12- or 24-month posttest. Children's understanding of hypothesis testing during each trial was again measured at three levels. The task used in this posttest was "Who took the gift?" (Figure 10).

The experimenter's series of questions served as implicit feedback as well as assessment of children's strategies. Children's strategies for testing a hypothesis were assessed at three levels at each trial. The most sophisticated and challenging level is the *Spontaneously Generating Hypothesis Test*. The hypothesis that a big bear was sinking the boats was provided, and children had to generate a conclusive test which involved leaving one of the boats in the water that only a big bear, but not a small bear, could sink. The experimenter first formed a hypothesis and asked the child to generate a test for the hypothesis: "The fisherman thought that the bear might be a big one. Now what could he do to find out whether it was a big bear that has sunken the boat overnight?" An example of a correct answer would be: "He would leave the biggest boat in the water, and if it was sunken by the morning, it must be a big bear that did it."

Given the scope of this chapter, we report results only concerning the most general and challenging level of assessment of children's strategies in testing hypotheses. Overall, children acquired hypothesis-testing strategies with experience. As Figure 11 shows, during the learning phase, second and first graders learned more effectively than kindergartners to spontaneously generate a hypothesis-testing strategy. Few children generated an appropriate test for the hypothesis on the first trial of the first task. However, even kindergartners improved their performance on the second trial and the subsequent tasks. Older children learned more effectively: across conditions, over four-fifth of the second graders and nearly two-thirds of the first graders generated an appropriate test, but only about one-fourth of kindergartners did so on the last task.

Different types of feedback from implicit to explicit (from implicit feedback from the specific questions that an experimenter asked, to more explicit feedback from physical demonstration, to very explicit feedback of verbal rationale) seem to have differential effects on learning at different age levels. Effects of condition were evident especially in kindergarten. Kindergartners in the verbal and physical feedback condition performed more effectively than those in the physical feedback condition, who in turn, performed better than those in the no feedback condition for Trial B of Task 1, and for Tasks 2 and 3. This indicated that explicit feedback (verbal and physical feedback) was more effective than the intermediate feedback (physical feedback), which was more effective than implicit feedback, especially for younger children. Nevertheless, even implicit feedback (either encountering the experimenters' specific questions or physical feedback) facilitated first graders in all three levels of understanding.

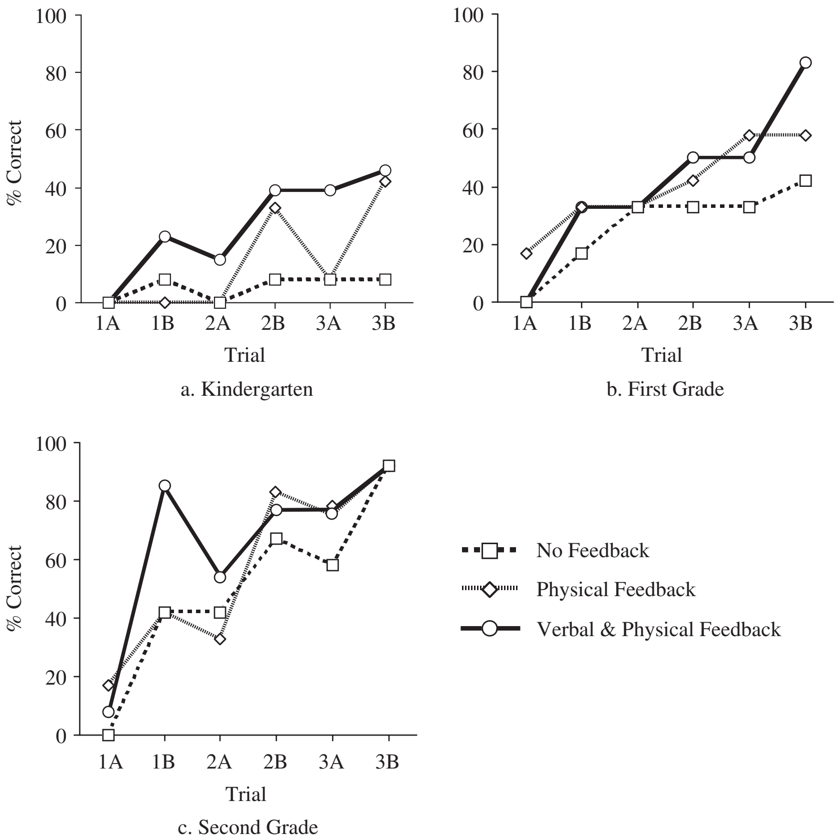


Fig. 11. Children's performance in generating a correct hypothesis test during the learning phase. Percent correct responses by trial and condition. (a) Kindergarten; (b) First grade; (c) Second grade.

One primary aim of this study was to examine whether children in the experimental conditions of the initial learning phase outperformed their peers who were not exposed to the initial tasks in the control condition. As shown in Panel a of Figure 12, when encountering the posttest task, few first graders in either condition on the 12-month-delay posttest spontaneously came up with correct hypothesis tests on the first trial. In contrast, about one-third of the second graders in the experimental condition used a correct hypothesis-testing strategy on the first trial, as compared to only a few of their peers in the control group. Converging results were also obtained on the 24-month-delay posttest (Panel b of Figure 12). These findings suggest that kindergartners and first graders learned

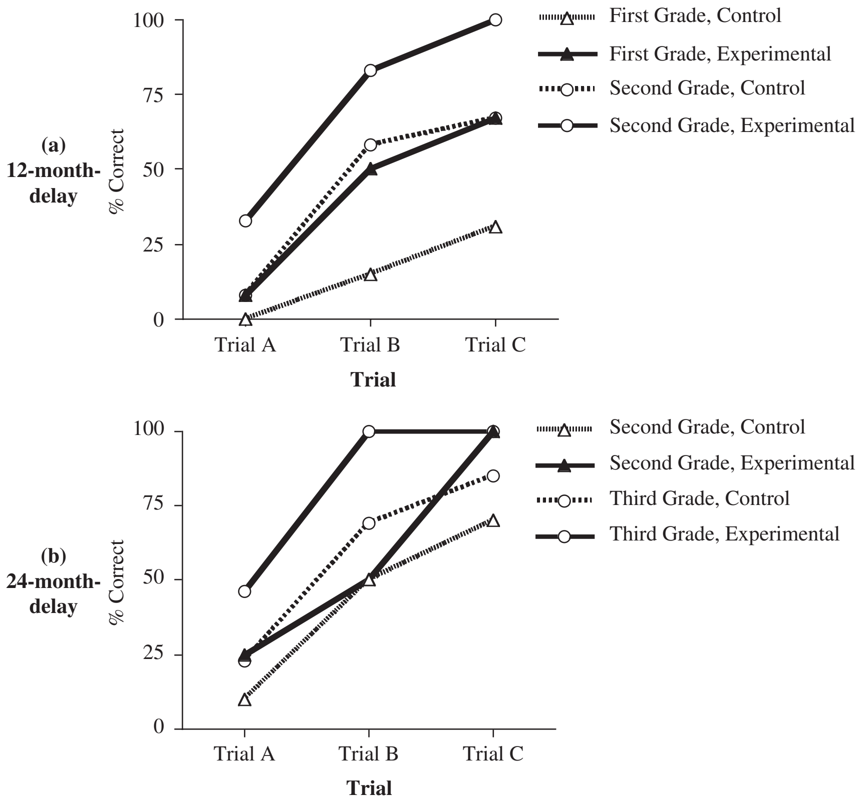


Fig. 12. Children's performance in generating a correct hypothesis test on the posttest after a 12-month or 24-month delay. Percent correct by grade and condition. (a) 12-month delay; (b) 24-month delay. Note: A portion of the kindergartners and first graders participated in a posttest after a 12-month or 24-month delay. Thus, the participants in the 12-month delay group (and the control group) were first and second graders when the posttest was performed, whereas the participants of the 24-month delay group (and the control group) were second and third graders.

hypothesis-testing strategies from the analogous tasks in the learning phase, and transferred the strategies when they encountered an isomorphic problem in a different context even after one or two years later.

Another aim was to compare children's performances between initial learning and transfer after a one- or two-year delay. The comparison focused on second graders' performance between the last (third) task (a total of two trials) during learning phase, the first two trials of the one-year-delay posttest, and the first two trials of the two-year-delay posttest. Second graders' strategies used to solve the third task during the learning phase were considered as near transfer because they had learned the hypothesis-testing strategy when solving the first two tasks. For the second graders (in the verbal and physical feedback and the physical feedback conditions when solving the third task, 85% of their strategies generated to test the hypotheses were correct (Figure 11, Panel c, combined over the two trials of the task), indicating that they readily transferred the hypothesis-testing strategy from the first and second to the third task during the learning phase. In contrast, second graders (who were first graders when participating in the learning phase) generated 58% correct strategies in solving the one-year-delay posttest task (Figure 12, Panel a, combined over the first two trials of the task), and second graders (who were kindergartners when participating in the learning phase) generated 38% correct strategies in solving the two-year-delay posttest task (Figure 12, Panel b, combined over the first two trials of the task).

This pattern of performance could be interpreted as differences between near and remote transfer, and between the one-year and two-year-delay posttests. The differences in transfer performance might have also been due to their differential initial learning, because the second graders whose performance was assessed on the first posttests were in first grade when they participated in the initial learning phase one year earlier, and the second graders whose performance was assessed on the second posttest were kindergartners when they participated in the initial learning phase two years earlier. This dilemma has not been resolved. Nevertheless, the performance pattern suggests that when time elapses, transfer performance declined. Moreover, although their long-term transfer performance was less impressive than their short-term transfer performance, young children nevertheless demonstrated the ability to generalize the learned hypothesis-testing strategy to different contexts even after a two-year delay.

The studies with an experimental approach described herein were designed to assess young children's remote transfer of scientific-reasoning strategies (e.g., CVS, hypothesis testing, and distinguishing determinacy/indeterminacy strategies) after long delays. The first experiment demonstrated that fourth graders readily transferred the strategy to design valid experiments from the original learning situation in the laboratory to the science classroom context 7 months later. The transfer between the initial learning and the posttest tasks in the first experiment involved substantial distance in all three dimensions: task and context similarity, and long temporal interval, as illustrated by point B in Figure 1. Third graders failed to transfer presumably because they might have failed to notice the similarities between the early hands-on tasks and the paper-and-pencil problems and/or because they experienced difficulties in executing the acquired strategies. We further examined even younger children's remote transfer by adapting an age-appropriate scientific-reasoning task in the study of young children's evaluation of indeterminate evidence. As illustrated by point C in Figure 1, the posttest problem was similar to one of the initial learning tasks, and encountered in a similar context. Kindergarteners proved capable of transferring a determinacy/indeterminacy-reasoning strategy learned 7 months earlier whereas 4-year-olds failed to do so even when the learning and testing tasks are very similar and administered in similar contexts. In the final experiment, on children's hypothesis testing, we extended these findings and tested more distant transfer in all three dimensions in kindergartners' and early elementary-school children. The transfer distance in this experiment is illustrated by point D, which represents substantial distance in task and contextual similarity, and in temporal interval (i.e., a 2-year time gap) between the learning phase and the posttest. Even kindergartners successfully transferred a hypothesis-testing strategy to structurally similar but superficially dissimilar task in a different context two years later. It was also evident that transfer distance in time gap influenced transfer performance.

Overall, these findings demonstrate that young children are able to transfer scientific-reasoning strategies acquired in one context to novel situations superficially different from the original context. Young children were able to retrieve relevant information and to use it to solve problems that were structurally similar but superficially dissimilar to those they encountered 6, 12, or even 24 months earlier in different contexts. These studies suggest that children's learning is broader and more flexible than previously assumed. The strategies that they learned do not automatically become constrained to the original learning situation, and they do not decay rapidly. Instead, children as young as five years of age proved capable of transferring acquired strategies to solve problems with different perceptual and contextual features with a time gap as long as two years.

IV. Evidence of Remote Transfer II: Naturalistic, Cross-Cultural Approach

Despite evidence of remote transfer from the studies described in Section III, the time gap between the learning and transfer was about only one or two years, and the contexts in which the strategies or concepts were learned and transferred typically involved in school settings, and thus were not substantially diverse after all. To overcome these limitations, we adopted a naturalistic, cross-cultural approach to address the issues of whether and how individuals retrieve and use source analogues that were acquired in naturalistic, specific cultural settings many years ago.

The naturalistic, cross-cultural studies were thus designed to explore long-term analogical transfer of problem solutions presented in folk tales that middle- and high-school students heard during their childhood. The transfer distance involved in the naturalistic cross-cultural study is therefore vastly more substantial than that involved in the experiments reported above in all three key dimensions, as illustrated by point E of Figure 1.

As mentioned previously and illustrated in Figure 1, the typical experimental paradigm for examining analogical problem solving involves presenting a source analogue and then a target problem shortly afterward within a lab setting. One reason for the predominant use of this paradigm is that it is impractical and unrealistic to provide a specific source problem and its solution, and then present analogous problems for participants to solve with an extended time gap in a different setting. It thus seems obvious that extending previous findings regarding analogical transfer to more naturalistic contexts and with more extensive time gaps between problems would have both theoretical and practical implications. Dunbar and colleagues (e.g., Dunbar, 2001) have explored how analogy is used "*in vivo,*" that is, in naturalistic settings, such as scientific laboratory meetings and political speeches. Blanchette and Dunbar (2001) observed use of analogies by leading molecular biologists and immunologists during their lab meetings and found that—unlike the typical scenarios manipulated by experimental psychologists, in which participants typically use source information to solve problems superficially similar to the source—real scientists in real working contexts often use structural features and higher-order relations in analogizing during the discovery process. In one example taken from their study, a scientist is investigating the way that HIV works and obtains a very strange result. To explain what happened, the scientist spontaneously draws an analogy to a genetic mechanism found in heat-resistant bacteria. Structural analogies thus are a frequent, rather than a rare, phenomenon when human reasoning and problem solving are investigated in naturalistic settings.

The difficulties of demonstrating analogical transfer in psychological experiments, along with the findings of rich use of analogy by Dunbar and colleagues, point to the importance of developing effective approaches to examine how analogical transfer occurs across contexts and with long delays. A naturalistic approach to explore analogical problem solving seems promising for overcoming these methodological limitations. Such a naturalistic approach allows the examination of analogical problem solving with more extensive time gaps and across contexts. Toward this end, Chen, Mo, and Honomichl (2004) conducted a series of studies using a novel method, which entails cross-cultural comparisons of problem solving. Specifically, middle-school, high-school, and college students from China were asked to solve a problem that was analogous to a widely known tale introduced in naturalistic settings, such as reading from a book or listening to a story during childhood many years ago. The target problem-solving performance of Chinese students was compared to those from a different culture (U.S.) who had never heard of the source story.

The source story problem was adopted from a Chinese tale, entitled ''Weigh the Elephant,'' which describes a scenario in which a Chinese emperor was faced with a difficult task of weighing a large elephant without the benefit of a proper scale. However, the emperor's son solved the problem by putting the elephant in a boat, marking the water level on the boat, and then replacing the elephant with small stones so that the water level reached the same mark (a compression strategy). The son then weighed the stones separately with a small scale and then totaled all the weights of the stones. Thus, this solution involves a principle of equalizing the weights of the smaller items and a large object by compressing the boat to the same degree. A preliminary study indicated that over 90% of Chinese students could recall the key elements (goal and solution) of the story, suggesting the availability of the source tale.

In an experiment with college students to determine the effects of culturally specific experience on long-term transfer across contexts, folk tales from China and the U.S. were chosen as source analogues. Target problems, which were isomorphic to the source tales, were created. One target problem, the ''statue'' problem, described a scenario in which a chief of a riverside village needed to find a way to measure an amount of gold commensurate in weight to a statue, without the benefit of a conventional balance scale. This problem was designed to be isomorphic to the well-known ''Weigh the Elephant'' tale. The solution involved a principle of equalizing the weights of the smaller items and a large object by compressing the boat to the same degree. Another target problem was the ''Cave'' problem, which described a scenario in which a treasure hunter needed to travel into a cave and then find his way out. The solution involved leaving a trail of sand while traveling through the cave and following this trail out to exit. The Cave Problem was created to be analogous to the tale ''Hansel and Gretel,'' by the Brothers Grimm, which is commonly read or heard by children in the U.S. but virtually unheard of by Chinese children. In the Hansel and Gretel tale, a brother and sister tried to find their way out of a forest by creating a trail with pebbles and bread crumbs.

The target problems and the source analogues involved similar solutions, but they shared few contextual and superficial features, such as similar objects and characters. Chinese college students, who had experienced the elephant tale as children, were predicted to be more likely than U.S.

students to come up with the compression solution to the Statue problem. Similarly, U.S. students, who almost certainly had heard the Hansel and Gretel story as children, were predicted to be more likely than Chinese students to solve the Cave Problem by creating a trail of small objects. Additional insight problems were chosen as "neutral" tasks, because of no known analogues to these problems in either culture. Examples of these problems included the radiation problem (Duncker, 1945; Gick & Holyoak, 1980) and the string problem (Maier, 1931). The radiation problem involved using a number of less-intense rays from different directions to converge on a tumor such that the rays effectively destroy the tumor without damaging the surrounding healthy tissue. The string problem involved grabbing two strings hanging apart from the ceiling by tying an available object to one string and swinging it. These control problems were used to test the hypothesis that performance on insight problem solving would be equivalent between the two cultures.

Substantial culture-specific analogical transfer was found when American and Chinese participants' performance was compared on isomorphs of problems based on European vs. Chinese folk tales. U.S. participants typically remembered the Hansel and Gretel story and solved the Cave Problem more effectively than Chinese students. Chinese participants usually remembered the elephant tales and outperformed U.S. students in solving the Statue problem (Figure 13). U.S. and Chinese participants were equally successful in solving the control problems, showing that differences in solving the target problems were not due to the cultural differences in general ability to solve insight problems. Instead, the complementary pattern of performance on the Statue and Cave Problems across the two samples provides clear and compelling evidence that participants are capable of drawing on culturally specific experience in solving analogous problems.

This study demonstrates college students' ability to access to and use of remote analogy in solving problems. Yet, despite that previous studies have shown that younger children are less likely to solve analogical problems, little is known concerning age differences in retrieving source information from long-term memory and in solving remote analogical problems. To address the issues of how middle- and high-school students differ in remote transfer, a developmental study was designed (Chen *et al.*, 2004). The experiment examined three issues: (1) the ability to analogize with a substantial time interval, (2) factors that influence long-term transfer processes (i.e., accessing the source information, mapping the key objects, and executing the solution strategy), and (3) age differences in long-term transfer among middle-school vs. high-school students.

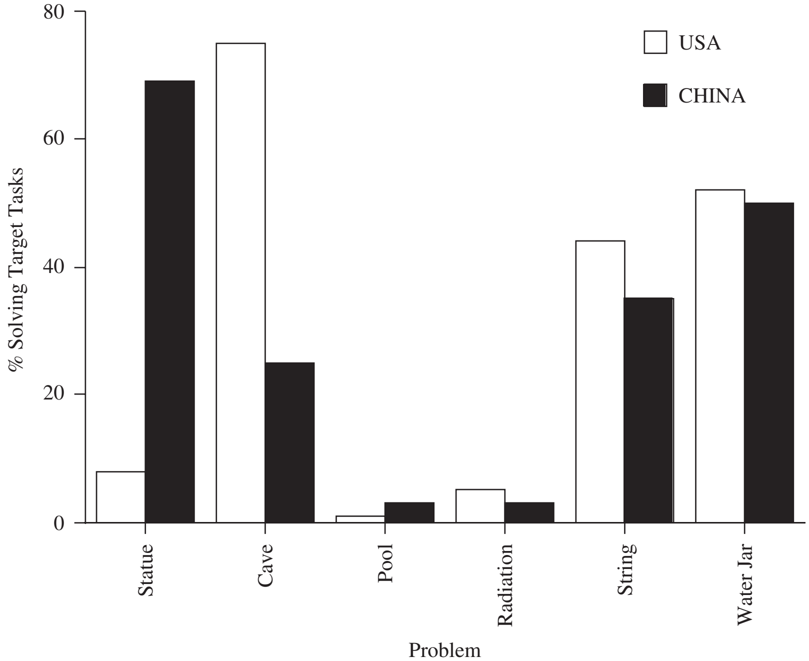


Fig. 13. Percentage of U.S. and Chinese participants solving the target tasks (the Cave and Statue Problems) and control problems.

Several versions of the target problem were designed by systematically varying the similarity in key objects between the source and target problems, specifically, the object needing to be weighed (elephant vs. asteroid) and the tool available to facilitate the compression strategy (boat vs. spring platform). This manipulation resulted in four versions of the target problems, with the elephant/boat version being the most similar to the original tale and the asteroid/spring version being the most dissimilar. These four conditions were similar goal object and similar solution tool, dissimilar goal object but similar solution tool, similar goal object but dissimilar solution tool, and dissimilar goal object and dissimilar solution tool.

Participants read a target problem and then viewed a set of illustrated objects that could potentially be used to solve the problem. Figure 14 illustrates the dissimilar goal object and dissimilar solution tool for the asteroid/spring problem. After attempting to solve the problem, participants were asked to answer several questions designed to reveal component processes involved in remote analogical transfer.

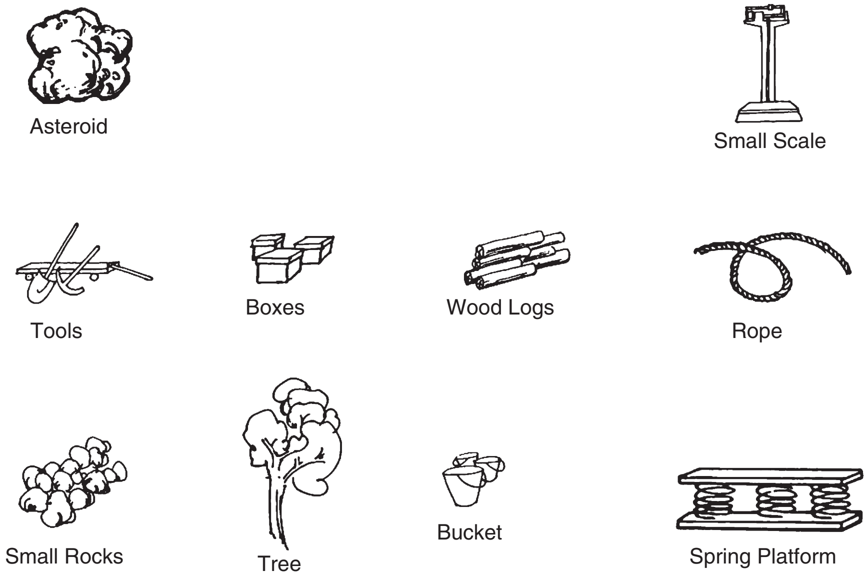


Fig. 14. An example of the target problem in the cross-cultural study: The asteroid/spring target problem.

The *representing* component was assessed by determining whether students recalled the goal and solution of the source tale. The *accessing* component was assessed by whether participants reported being reminded of the tale as they solved the problem. The *mapping* process was measured by participants' selection of both the goal object and the solution tool during problem solving. The *executing* component was measured by the participants' accurate use of the weight compression and equivalence principles with the solution tool. Finally, the *evaluating* component was measured by the students' judgment of how much the source analogue had helped them solve the target problem.

It is important to note that the actual order of assessing the participants' problem-solving activities does not correspond to the order of presenting these five measures. Participants were first asked to attempt to solve the target problem before being asked to report any potentially relevant source stories, to evaluate the usefulness of the reported source analogue, and to recall the source tale. For theoretical reasons, data analyses are presented in the order of recalling, accessing, mapping, executing, and evaluating, which is the sequence in which these processes are hypothesized to occur.

The results revealed that that both age groups remembered the source story well (memory score of 1.84 out of 2), indicating that the source story was well represented in long-term memory. Overall, 10th graders (85%) were more likely than 7th graders (68%) to access the source story during problem solving, but children retrieved the source story differently in different conditions. At both grades, students in the dissimilar goals and dissimilar tools condition were less likely to access the source problem than the other conditions. That is, students were least likely to retrieve the folk tale spontaneously when the problem to be solved had a different goal and a different tool. Regarding mapping, at both grades students typically mapped the key items when problems involved similar goals and similar tools but were much less likely to map correctly when problems involved dissimilar goals and dissimilar solution tools. At both ages, students were most likely to solve problems involving similar goals similar tools but least likely to solve them when they involved different goals and tools. Similarly, students rated the source tale to be most helpful on problems with similar goals and tools but least helpful for problems with dissimilar goals and tools.

These results indicate that both middle- and high-school students had little difficulty in recalling the source story. The pattern of accessing the source analogue across the four conditions was similar to that in college students: dissimilarity in both goal object and solution tool hindered the accessing process. Middle-school students performed as well as high-school students when the problems shared both a common goal object and solution tool. However, they were less likely to access the source story, to map the key objects, and to execute the solution when the objects, especially the solution tool, were different between the problems. Despite the developmental differences in these measures, even middle-school students showed the ability to transfer the solution from a source analogue acquired from the distant past in different contexts.

The naturalistic, cross-cultural approach proved effective in exploring remote analogical transfer of problem solutions that participants had heard in folk tales during their childhood, many years before encountering the target problems. Substantial culture-specific analogical transfer was found when American and Chinese participants' performance was compared on isomorphs of problems solved in European vs. Chinese folk tales. Comparisons of different versions of the target problems indicate that similarity of solution tool affected the accessing, mapping, and executing components of problem solving, whereas similarity of goal object had only a moderate effect on accessing. Developmental differences in remote transfer were also evidenced. These findings demonstrate that source analogues can be acquired in various cultural settings, the conceptual information can be represented, and the solution strategies can be transferred to novel problems in different contexts after a substantial delay.

V. Processes Involved in Remote Transfer

The studies described here not only demonstrated the existence of remote transfer, but also revealed the processes involved in transfer. Previous studies in analogical problem solving have identified, in separate contexts or tasks, three key components involved in transfer: *accessing* a source problem, *mapping* the structural relations, and *executing* a solution or strategy (e.g., Gentner & Toupin, 1986; Reed & Bolstad, 1991; Ross, 1989). In the cross-cultural studies, we examined the contributions of all three components involved in remote transfer in the same task by making finer distinctions between types of object similarity and exploring the influence of different types of object similarity on various processes involved in analogical problem solving.

A. ENCODING FEATURES OF SOURCE ANALOGUES

The first component involved in remote transfer is representing the source analogues; the issue concerns what information is encoded from the original learning situations, and how it is stored in long-term memory. The effects of source representation quality on subsequent transfer have been demonstrated in earlier studies wherein children who formed an abstract schema of the source solutions showed greater transfer than children who encoded a problem's specific details (Brown *et al.*, 1986; Chen & Daehler, 1989). The findings summarized in Section IV indicate that children readily recalled source analogues and transfer learned strategies to remote situations after long delays, suggesting that they represented and stored the original learning tasks in such a way that the solutions/strategies could be retrieved and used when encountering structurally similar problems. For example, in the cross-cultural research, students in the similar object conditions outperformed those in the dissimilar object conditions, who outperformed those in the control condition (their peers in another culture who had never heard the source analogue). These results suggest that children's representations of source analogues contain elements of both superficial and structural features in long-term memory. Thus, either type of feature can serve as a retrieval cue to activate the representation.

B. ACCESSING SOURCE INFORMATION

The initial process of transfer involves searching for relevant information, such as similar events, instances, or stories in long-term memory at the appropriate time. One cue for such experiences is *object reminding*. The presence of common object attributes between an earlier source problem and current target problem increases the likelihood of retrieving a source analogue. Previous work with short-term analogical transfer has yielded consistent findings concerning the effects of superficial similarity on accessibility (e.g., Brown & Campione, 1981, 1984; Crisafi & Brown, 1986; Daehler & Chen, 1993; Gentner *et al.*, 1993; Wharton *et al.*, 1994). In the cross-cultural study, sharing either goal object or solution tool proved sufficient to increase the accessibility of the source tale, suggesting that both were equally effective in reminding. These results suggest that representations of source analogues contain object-specific information about a story or problem situation and, thus, object cues in a target problem may trigger the retrieval of a source analogue.

Another avenue of accessing relevant information involves structural reminding, which involves mapping the higher-order relations of the key entities between the source and target problems. Models of artificial intelligence and case-based reasoning view the process of human memory retrieval as typically driven by higher-order causal or goal structures (e.g., Hammond, Seifert, & Gray, 1991; Kolodner, 1993; Schank, 1982), implying that individuals are capable of accessing knowledge in long-term memory based on higher-order structural similarity. Over two-thirds of the Chinese students in the cross-cultural study retrieved the elephant tale from long-term memory; the goal structure of the asteroid/spring problem (e.g., the scientists needed to figure out the weight of the asteroid) reminded the Chinese participants of elephant tale, even though the target shared few common object attributes with the source.

The findings from the experiments on transfer of scientific-reasoning strategies also expand previous findings by demonstrating that common goal structures can play a central role in guiding accessing when solving analogical problems after long delays. Even young children spontaneously retrieved acquired strategies from long-term memory and used them to solve isomorphic tasks that shared few similar surface features in new contexts after a long delay.

C. MAPPING STRUCTURAL ELEMENTS BETWEEN PROBLEMS

After a source analogue has been retrieved, solvers still need to match the corresponding elements or objects between problems. Mapping problems has been found to be guided by the common relational structures between analogous tasks (e.g., Chen & Daehler, 1992; Clement & Gentner, 1991; Gentner *et al.*, 1993; Goswami, 1995). In the cross-cultural research, mapping was assessed by the students' choice of goal object and solution tool during problem solving. In analogical problem solving, the selection of the corresponding target objects ultimately reflects the mapping of the structures between problems. After the relevant source story or event is retrieved, the common structural relations of the entities or objects associated with the entities between the problems serve as guides for matching the problems (e.g., Gentner & Markman, 1997). The present research further demonstrates that different types of object similarity play distinctive roles in transfer. Although solution tool similarity played a critical role in the mapping process, goal object commonality did not appear to influence how the key elements were mapped between problems.

D. EXECUTING A LEARNED SOLUTION

Accessing an analogue and mapping the corresponding elements between source and target problem structures do not ensure successful execution of a solution retrieved from long-term memory. Previous studies have shown that when source and target problems share a solution principle but differ in specific procedures, individuals are less likely to implement a source solution (e.g., Chen, 1996, 2002; Reed & Bolstad, 1991; Ross, 1989). The cross-cultural study results further reveal that participants can also suffer an execution deficiency when the solution tool for the target problem differs in attributes from the source tool. The likely reason why only the solution tool is associated with the executing component is that the solution tool, and not the goal object, serves as a crucial part of the causal path, whereas goal object is arbitrary: Any object can be weighed with compression, but only objects that can be compressed may serve as a solution tool. Furthermore, the goal object is selected automatically, whereas there are alternatives from which a solution tool can be chosen and utilized to generate a solution procedure.

This conceptual model concerning the processes involved in remote transfer addresses the observation that individuals often experience difficulty with analogical transfer after a long delay and that younger children in particular often fail to solve problems by remote analogy. This model also addresses questions of why some analogues are more difficult to use in problem solving than others. And as we demonstrate in the next section, the model helps pinpoint how children at different age levels differ in solving remote, analogous tasks, and how various factors influence children's performance on remote transfer.

VI. Developmental Differences

One striking aspect of age differences in learning and thinking involves the ability to generalize acquired strategies to other tasks and situations. Earlier studies indicate noticeable developmental differences. Younger children's learning is more perceptually bound and more greatly influenced by the superficial features of problems than by their structural or causal properties (Chen, 1996; Chen, Yanowitz, & Daehler, 1995; Daehler & Chen, 1993; Gentner & Markman, 1997). Furthermore, to draw the analogy between source and target problems younger children tend to need explicit hints or aids that point out the usefulness of prior problems (Brown *et al.*, 1986; Chen, Sanchez, & Campbell, 1997; Crisafi & Brown, 1986; Holyoak, Junn, & Billman, 1984). With age, children become increasingly more effective in perceiving deep relations or causal structures (e.g., Gentner & Toupin, 1986), and hence rely less on surface commonalities or explicit hints as vehicles to draw analogies (e.g., Chen, 1996; Daehler & Chen, 1993; Vosniadou, 1987).

Developmental differences are evident in both the experimental and cross-cultural studies summarized herein. With age, children's transfer of strategies and concepts is increasingly broad, flexible, and effective. In the research described in Section III, 5-year-old children who acquired the determinacy/indeterminacy expert rule from the learning phases continued to use it during the immediate posttest phase and the follow-up phase 7 months later. These results demonstrate kindergartners' ability to generalize the acquired rule even after a long delay, and preschoolers' difficulty in generalizing as the gap between the learning situation and the new problems became more distant. Thus, feedback proved effective for 5-year-olds but had no lasting effects on younger children. Likewise, for more complex tasks, third graders demonstrated the ability to transfer CVS across tasks within the domain of mechanics (i.e., when reasoning about springs, slopes, and sinking tasks) and after a short delay (within a week), but only fourth graders displayed remote transfer.

One reason for developmental differences in the breadth of learning is related to differences in the depth of initial learning (e.g., Siegler, 2000, 2005). Older children's more "robust learning" in terms of acquiring the effective strategies in solving the original problems might explain their better retention and wider generalization on relatively near transfer tasks. Older children show broader learning than younger ones (e.g., Bjorklund, 1988; Chen & Siegler, 2000; Dixon & Bangert, 2002; Schauble, 1996) because they master the original tasks to a greater extent. When younger and older children learn an initial task to the same extent, they demonstrate comparable transfer (e.g., Brown *et al.*, 1986; Chletos & De Lisi, 1991; Crowley & Siegler, 1999).

However, the research reported herein suggest that age differences in generalizing learned strategies across contexts after long delays are not due solely to differences in original learning. The cross-cultural studies showed that although middle- and high-school students recalled the source tale equally well, nevertheless high-school students were more successful than middle-school students in retrieving the analogue, mapping the key entities, and executing the solution strategy. The experimental studies described herein also indicate that even when children at different age levels acquired equally well the determinacy/indeterminacy rule, the hypothesis-testing strategies, or CVS during the original learning phase, older children nevertheless demonstrated higher efficiency in extending the strategies to other situations. When the transfer gap becomes increasingly distant, developmental differences in transfer become increasingly apparent.

What are the processes involved in developmental differences in remote transfer? The cross-cultural research helps pinpoint how age differences may be associated with each component of remote transfer. We explored the contributions of all three key components on a single task of long-term analogical problem solving and found that age differences were evident with all the key processes: Middle-school students were more likely than high-school students to experience difficulties in accessing the source problem, in mapping the key objects between the problems, and in executing the source solution, especially in the dissimilar solution tool conditions. Despite the availability of the source tale in long-term memory, some young participants failed to come up with an appropriate solution because they failed to *access* the source story from long-term memory when they encountered the target problem. Others did not use the source analogue because they experienced difficulties in *mapping* the entities of the source story onto the target problem, thus failing to choose a novel tool that matched the boat in function, but not in attributes. Yet, others failed to *execute* the acquired analogous solution, due to their using the selected tool inaccurately.

Despite the fact that high-school students had heard of the source analogue in the more distant past, they nevertheless were more likely to access and use it to solve a target problem than middle-school students. A likely explanation for this result is that the goal structure of the problem (i.e., the goal to weigh a large and heavy object, and obstacle of figuring out the weight with a small scale, and the approach to overcoming the obstacle) are strengthened, and the solution strategies (i.e., weight compression and equivalence principles) are further instantiated with relevant experience with age. With age and experience, the representation of the source analogue becomes increasingly accessible, and applicable, and the generalization of acquired source strategies becomes increasingly effective, flexible, and broad.

VII. Educational Implications

Age is not the only factor that influences remote transfer. It is evident in this series of studies that how children represented and processed the source analogues largely determined how long the learned strategies could be maintained and how widely the strategies could be generalized. The studies described here have generated findings concerning factors influencing remote transfer in children, and have important implications concerning the role of analogy, instruction, implicit feedback, self-explanation, and learning in naturalistic and cultural settings.

A. ROLE OF ANALOGY

Analogy is a powerful heuristic for learning and transfer of scientific-reasoning strategies. Children as young as five are capable of representing the underlying structures of the determinacy/indeterminacy problems during initial learning and of mapping the structures between the initial tasks and the target problems encountered several months later. Elementary-school children successfully applied CVS across problems with different formats and in different domains after a long delay. Likewise, kindergartners and first graders also proved quite effective in learning to understand the fundamental principle of testing a hypothesis and in transferring the correct strategy by mapping the problems presented one or two years apart. The present results extend previous findings concerning children's ability to solve problems by analogy (e.g., Brown, 1989; Brown & Kane, 1988; Chen & Daehler, 1989; Gentner & Markman, 1997; Goswami, 1991, 1996; Tunteler & Resing, 2002) and indicate that analogical reasoning plays a central role in remote transfer. By embedding the tasks and strategies in the different surface features and contexts, we helped children construct a schema that could be generalized to tasks with new features and settings (e.g., Brown *et al*., 1986; Butterfield, Slocum, & Nelson, 1993; Chen & Daehler, 1989; Gentner, 1983, 1989; Gick & Holyoak, 1983).

B. EXPLICIT INSTRUCTION

The extensive controversy about the benefits and costs of instruction located at various points along the direct instruction and discovery spectrum (e.g., Kirschner, Sweller, & Clark, 2006; Mayer, 2004) raises the issue about what is learned and how the learned strategies are transferred with various instructional approaches. Some studies have claimed that students who discover new concepts or strategies are more likely to extend this knowledge to new tasks than those students who learn from direct instruction (e.g., McDaniel & Schlager, 1990; Stohr-Hunt, 1996). Many argue that children tend to acquire superficial and short-lived knowledge when direct instruction is involved, as compared to discovery. However, few previous studies have examined the long-term effects of explicit instruction and discovery.

In the remote transfer studies described herein, it is evident that explicit instruction has been shown to be an effective approach in facilitating the acquisition and transfer of a hypothesis-testing strategy, in teaching elementary-school students to design unconfounded experiments, and in helping 4- and 5-year-old's learn the principles of determinacy/indeterminacy. Elementary-school children can overcome what appear to be stubborn misconceptions when they receive instruction and explicit feedback (Chen & Klahr, 1999; Klahr & Carver, 1988; Klahr & Nigam, 2004; Siegler, 1996; Siegler & Chen, 1998). The present results also show that with appropriate instruction, elementary-school children are capable of understanding, learning, and transferring the basic strategy when designing and evaluating simple tests. Children in the training-probe condition increased their use of CVS from 34% of the trials in the Exploration phase (before training) to 65% in the Assessment phase within the task (after training), and to 61% and 64% of the trials across tasks in the Transfer I and II phases, respectively. In these cases, the nature of the CVS tasks made it very difficult for self-directed and self-correction to take place, especially for younger children. The indeterminacy study also demonstrates that even younger children are capable of acquiring a difficult reasoning strategy from explicit feedback and are able to transfer the learned strategy to different contexts even after a 7-month delay. Problem-solving experience alone did not greatly facilitate children's understanding of indeterminate patterns, presumably because the outcome of subsequent box openings did not provide sufficiently consistent or salient feedback. In contrast, explicit training pinpointing the rationale was effective in facilitating the acquisition of understanding indeterminate patterns.

C. IMPLICIT FEEDBACK AND SELF-EXPLANATIONS

Direct instruction is not the only effective way to facilitate learning and transfer in young children. In the example of overcoming the positive-capture strategy, 5-year-olds learned from instruction, but their learning and transfer across isomorphic tasks also benefited from extended problem-solving experience, even in the absence of explicit instruction. The effects of implicit feedback were also evident in young children's learning of hypothesis-testing strategies, as young children's transfer of the strategies benefited from demonstrations with toy props, and from implicit probe questions.

The effects of implicit feedback on learning and transfer are likely due to the benefit from children's self-explanations. For example, when learning CVS, children in the no training-probe condition were asked systematic questions on each trial about why they designed the test they did. Children thus had the opportunity to generate explanations of their reasoning behind their choice of objects for their experiment and for the possible conclusions from their design. Children's superior performance in learning and transferring CVS in the probe condition, as compared to the no probe condition, replicates a growing body of studies demonstrating that the opportunity to generate self-explanations enhances learning (e.g., Chi *et al.*, 1994; Honomichl & Chen, 2006; Renkl, 2002; Rittle-Johnson, 2006; Siegler, 2002; Siegler & Chen, 1998). The power of self-explanation has not been demonstrated for long-term transfer; our studies extend prior research in indicating that asking children to explain their own responses benefits remote transfer.

D. LEARNING IN NATURALISTIC AND CULTURAL SETTINGS

Another implication of the present studies is that children learn effectively in naturalistic settings and can readily transfer their learning to remote situations. Our cross-cultural research provides compelling evidence for remote transfer in that the source and target problems shared few semantic and contextual features. Even with a significant time gap between source and target problems, solvers can be reminded of the source analogue and can use it effectively when encountering an isomorphic problem in a different context. Although the most accurate performance occurred when common objects were shared between problems, the analogous target problem did not share key object attributes with the source analogue in long-term memory.

The lack of efficient transfer found in previous laboratory studies even with adults (e.g., Perkins & Grotzer, 1997; Reed, Ernst, & Banerji, 1974) and the robust use of remote analogy evident in the present research seems to present a paradox. Yet, as Dunbar (2001) has pointed out, structural analogies are a frequent rather than a rare phenomenon when reasoning is investigated in naturalistic environments. For example, it was found that scientists often use structural features and higher-order relations in analogizing during the discovery process (Dunbar & Blanchette, 2001). Findings summarized here confirm that source analogues can be acquired in various cultural settings, represented in rich ways, and transferred to novel problems in different contexts after a substantial delay. The implication about how cultural experiences influence thinking is that children often acquire solutions and strategies in naturalistic settings, and the acquired information is durable, accessible, and applicable.

VIII. Conclusions and Future Directions

Whether and how children can flexibly retrieve relevant information from long-term memory and generalize the acquired strategies to broad situations is a fundamental issue in human cognition, children's learning, and education. And yet, there are virtually no studies addressing the issues of whether and how children transfer strategies across contexts after a prolonged delay. In this chapter we have reviewed a number of studies in which we attempted a multi-faceted exploration of remote transfer, using a traditional experimental approach and a naturalistic, cross-cultural approach. These studies represent an effort to bridge the gap between the central role of remote transfer in human cognition and children's thinking and our as yet limited knowledge of children's competencies and processes in remote transfer. These studies focus on the impact of time and context on children's transfer of scientific reasoning- and problem-solving strategies from initial learning situations to target tasks that share few superficial and contextual features.

These studies suggest that despite the theoretical and methodological difficulties, remote transfer is documentable, and the findings of children's transfer of strategies to remote situations are robust. Furthermore, the findings described here have yielded theoretical implications. The first implication concerns the nature of representations. The issue is which information is encoded and stored in long-term memory and how. The results suggest that representations of the source examples contain both structural and surface features in long-term memory and that either type of feature can serve as retrieval cue to activate the representation. The second implication concerns the nature of developmental differences. Age differences in remote transfer performance may be due to both the quality of the initial representations of the source analogue, and the ability to retrieve, map, and execute the source strategy when children encounter an isomorphic problem. With age and experience, children are increasingly able to encode analogues more deeply and to use the source information to solve target problems more flexibly and effectively. The third implication concerns how cultural experiences influence thinking. Many studies have indicated that cultural values, systems, and practices influence cognitive styles and performance. The present findings suggest that differences in cognitive strategies and performance are traceable to specific cultural experiences, which may be richly represented, flexibly retrieved, and effectively used in different contexts when appropriate. Finally, the fourth implication concerns whether and how the distant gap between source analogues and target problems can be crossed by encouraging children to represent deeper structural features and extract more general principles from the analogues.

The studies described herein are only initial steps in exploring remote transfer in children. With the "rebirth" of research in children's learning (Siegler, 2000, 2006), we expect to see more studies on children's transfer and generalization of strategies, and research in issues related to remote analogical transfer is beginning to flourish. Interesting avenues for further exploration of children's remote transfer involve effects of dimensions of transfer distance on performance, early abilities of transfer, nature of remote transfer, and factors that promote distant transfer. One future direction involves finer analyses and systematic manipulations of different dimensions of transfer distance. The proposed transfer distance space as illustrated in Figure 1 is only an initial step toward our understanding of remote transfer. It remains a critical task to refine the effects of each dimension of transfer distance (task similarity, context similarity, and time gap) and the interaction between them on transfer performance in children at different ages.

A second direction for future studies concerns the abilities of preschoolers, toddlers, and even infants to retrieve and use acquired strategies. Even infants and toddlers can demonstrate near analogical transfer, such as transfer of problem-solving strategies across analogous tasks within the same lab context and within the same hour or same day (e.g., Brown, 1989; Chen & Siegler, 2000; Chen *et al.*, 1997), but the question of whether, with age-appropriate tasks, very young children are capable of demonstrating remote transfer remains unexplored. Even for very young children, experiences inevitably influence their thinking and learning; however, it remains to be seen how flexibly and widely young children's experiences in problem solving is generalizable to tasks in different contexts and with long delays.

A third direction for further exploration of remote transfer is related to the implicit and explicit nature of analogical transfer. Although both implicit and explicit use of analogies in solving problems have been evident in adults (e.g., Schunn & Dunbar, 1996), we do not yet fully understand (a) the extent to which children retrieve and use source analogues explicitly or only implicitly, (b) when and how they gain metacognitive and explicit understanding of analogical relations between problems, or (c) what factors (e.g., task and context similarity, time gap, and feedback during initial learning) influence the explicit retrieval and use of remote source analogues in children at different ages.

A fourth avenue for further study is to explore how optimal remote transfer can be promoted. The precise roles of instruction, guided discovery, and self-explanation in remote transfer processes remain to be examined. Exploration of these issues of children's remote transfer will yield significant theoretical and educational implications for children's thinking and learning. As we uncover ever more fully answers to these questions, our own theoretical, empirical, and pedagogical knowledge will become more complete, thereby enhancing our endeavors not only to understand but, more importantly, to enrich children's thinking and learning experiences.

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Richland, 2007.

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