CHAPTER 5

Strategy Choices in Children's Time-Telling*

INTRODUCTION

When just beginning to learn to solve a class of problems, people often know only a single problem-solving strategy. For example, when beginning to learn to add, children often can only solve problems by counting their fingers. By the time people have acquired a high degree of skill in the area, they often consistently use a single efficient procedure. Continuing with the addition example, adults and older children consistently solve simple addition problems by retrieving answers. During the transition period, however, people often use a variety of strategies. While in the midst of learning to add, children solve simple addition problems by counting from one, by counting from the larger addend, by decomposing problems into simpler forms, and by retrieving answers from memory (Fuson, 1982; Baroody & Ginsburg, 1986; Siegler, 1987a). A central assumption of the

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present research is that for many cognitive acquisitions, understanding of transitions demands understanding of the diverse strategies that children use in the transitional periods.

The fact that children who are in transitional periods often use diverse strategies raises a number of questions. What strategies do they use; what benefits do they obtain from using the diverse strategies; how do they choose among them? These issues have been addressed previously in the context of addition, subtraction, and multiplication (Siegler, 1987b; 1988; Siegler & Shrager, 1984; Siegler & Robinson, 1982). In the research described in this chapter, we extend the examination of strategy use and strategy choice to time-telling on a conventional analog clock.

Time-telling is of interest for both theoretical and practical reasons. Everyday observation indicates that children who are learning to tell time use several strategies. They sometimes count forward by 5's from the previous hour, sometimes count forward by 5's from other points on the clock, and sometimes retrieve the time from seeing the configuration of the hour and minute hands. Time-telling also is of interest because of its relation to the previously-studied arithmetic tasks. It is like them in that it involves numbers and counting, but differs in that it appears also to involve a substantial perceptual-recognition component. Thus, it provides a test of whether a model developed to account for strategy choices in arithmetic also is useful outside of the arithmetic domain. Finally, time-telling is a task of considerable practical importance, one to which children devote a large amount of time both in and out of school, and one about which little is currently known. The basic descriptive data on the development of time-telling skills should be valuable independent of the success of the model in accounting for them.

The chapter begins with a discussion of two literatures. One focuses on the general issue of how people choose strategies. The other focuses on the development of time-telling skills. Next, we describe an experiment intended to document which strategies children use to tell time, how often each strategy is used, how accurately and rapidly each one is used, and the conditions under which each strategy tends to be used. Finally, we examine the ability of the strategy-choice model to account for children's time-telling performance.

A SHORT REVIEW OF THE LITERATURES ON STRATEGY CHOICE AND TIME-TELLING

The Issue of Strategy Choice

Traditionally, cognitive and developmental psychologists have tried to determine the strategy that people use on a certain task. This approach has led to many influential models, among them models of sentence verification (Clark & Chase, 1972; Carpenter & Just, 1975; Trabasso, Rollins, & Shaughnessy, 1971), mental rotation (Cooper & Shepard, 1973; Shepard & Metzler, 1971), transitive inference (Clark, 1969, Huttenlocher & Higgins, 1971; Sternberg, 1977), and addition of numbers (Ashcraft, 1982; Green & Parkman, 1972).

Recently, however, increasing numbers of researchers have recognized that people use diverse strategies on many tasks, including those where single strategies were previously assumed. Hunt and his colleagues demonstrated that different people use different approaches to verify sentences (MacLeod et al., 1978; Matthews, Hunt, & MacLeod, 1980). Cooper and her colleagues described alternative strategies that people use to perform mental rotation (Cooper & Regan, 1982; Glushko & Cooper, 1978). Egan and Grimes-Farrow (1982) and Sternberg and Weil (1980) identified several strategies that people use to draw transitive inferences.

It is not only true that people of different ages and abilities use different strategies to perform a single task; it also is true that individuals use multiple strategies. The majority of kindergarteners, first graders, and second graders have been found to use at least three addition strategies (Fuson, 1982). The majority of kindergarteners and first graders have been found to use at least three subtraction strategies (Siegler, 1987b). The majority of third graders have been found to use at least three multiplication strategies (Siegler, 1988). The phenomenon does not only reflect children using different strategies on different problems. When presented the identical subtraction problems a week later, kindergarteners and first graders used visibly different strategies on 34% of problems (Siegler, 1987b). Thus, variability of strategy use exists even within a single child solving the identical problem at two points close in time, when knowledge and general cognitive level are essentially constant.

To accurately represent what people are doing, cognitive models must incorporate this variable strategy use. Failing to do so can lead to severe distortions. For example, one of the best known and most extensively documented cognitive-psychological models is Green and Parkman's (1972)
min model. It posits that first and second graders solve essentially all single digit addition problems by counting up from the larger addend. Thus, they would solve 3+6 by thinking “6, 7, 8, 9”. The min model predicts that solution times and percentage of errors on each problem will be a linear function of the smaller addend, because the smaller addend indicates the amount of counting-on from the larger number that needs to be done to solve the problem. This prediction has proved accurate for both groups of children and individuals, in both Europe and North America, in both standard and special education settings (see Ashcraft, 1987, for a review of this literature).

Despite all this support, the model is wrong. In a recent experiment, Siegler (1987a) examined young children’s simple addition, using both the usual solution-time and error measures and children’s verbal reports. The results were striking. When data were averaged over all trials, as in earlier studies, the results closely replicated the previous finding that solution times and percentage of errors were a linear function of the smaller addend. If these analyses were the only ones conducted, the usual conclusion would have been reached, namely that first and second graders consistently use the min strategy to add.

However, the children’s verbal reports suggested a quite different picture. The min strategy was but one of five approaches that they reported using. This reporting of diverse strategies characterized individual as well as group performance; most children reported using at least three approaches. Not only did children not report using the min strategy on every trial, they only said they had used it on 36% of trials. At no age did they report using it on more than 40% of trials.

Dividing the error and solution time data according to what strategy children said they had used on that trial lent considerable credence to the children’s verbal reports. On trials where they reported using the min strategy, the min model was an even better predictor of solution times than in past studies or in the present data set as a whole; it accounted for 86% of the variance in solution times. In contrast, on trials where they reported using one of the other strategies, the min model was never a good predictor of performance, either in absolute terms or relative to other predictors. It never accounted for as much as 40% of the variance. A variety of measures converged on the conclusion that children used the five strategies that they reported using, and that they employed them on those trials where they said they had. Thus, it appeared that the min model misrepresented what children were doing on almost two-thirds of trials.

The general point is that people in the process of learning often use multiple strategies and that failing to recognize this can lead to seriously incorrect conclusions. Only by taking seriously the diversity of strategy use, even within a single person, can cognitive models hope to characterize transition periods accurately.

THE ADAPTIVE VALUE OF USING DIVERSE STRATEGIES

Once the diversity of people’s strategy use is recognized, the question immediately arises: What function does the diverse strategy use serve? Considering the patterns of speed and accuracy produced by each strategy suggests that children derive substantial advantages from using multiple strategies. This can be seen especially clearly in the choice of whether to state a retrieved answer or to use a backup strategy. A backup strategy is defined as any strategy other than retrieval; thus probability of backup strategy use is always 1 minus probability of retrieval. Examples of backup strategies include counting fingers to add, sounding out words to read, looking up a word’s spelling in a dictionary, and so on. Both retrieval and use of backup strategies have clear, though different, advantages for someone in the process of acquiring a new competence. Retrieval can be executed much faster, but the backup strategies often yield high accuracy rates on problems where retrieval cannot. Ideally, children would use retrieval where that faster approach could be executed accurately, and would use backup strategies where the backup strategies were necessary for accurate performance. In fact, children’s strategy choices have followed exactly this pattern in the domains we have studied. On easy problems children rely primarily on retrieval; on difficult problems, they rely primarily on backup strategies.

Comparing children’s behavior under conditions where they are and are not allowed to use such backup strategies reveals just how adaptive the children’s strategy choices are. Allowing children to use backup strategies leads to more accurate performance on all problems. However, the degree of the advantage for each problem is closely related to how often children use backup strategies on that problem when allowed to do so. That is, on problems where children are much more accurate when they use backup strategies, they use them often. On problems where children are only slightly more accurate when they use backup strategies, they use them much less often.

This pattern of strategy use allows children to strike an effective balance between concerns of speed and accuracy. They wind up using the fastest strategy, retrieval, when they can do so accurately, and using slower backup strategies when such strategies are necessary for accurate performance. The question is how children are able to make such adaptive strategy choices.
TWO APPROACHES TO HOW PEOPLE CHOOSE STRATEGIES

Given that people have a number of strategies at their disposal, how do they decide which one to use in a particular situation? Two approaches to this question can be contrasted: models emphasizing rational use of explicit, stable, metacognitive knowledge about cognitive capacity, available strategies, and task demands, and models emphasizing the adaptive products that fall out of the workings of basic cognitive processes.

APPROACHES EMPHASIZING EXPPLICIT KNOWLEDGE. One way in which children could choose strategies would be to explicitly consider metacognitive knowledge about the difficulty of problems, their own memory capacity, and available strategies. For example, given the task of determining what time it was when an analog clock said 4:25, a child might judge the difficulty of the problem, ponder available strategies, and decide which strategy should be used given the characteristics of the problem and the available strategies.

Although depictions emphasizing such rational, top-down decision processes are appealing, their value as a general model of strategy choice has been increasingly questioned. The criticism has focused both on the frequent lack of empirical connections between explicit, stable metacognitive knowledge and strategic behavior (Brown & Reeve, 1986; Chi & Ceci, 1987; Cavanaugh & Perlmutter, 1982; Sternberg & Powell, 1983), and on the vagueness of theoretical ideas about how metacognitive knowledge might exert its effect. Although children clearly have such metacognitive knowledge, it remains unclear when such knowledge is involved in strategy choices and what role it plays when it is involved.

The present approach is based on a different assumption: that at least some strategy choices are not based on such explicit metacognitive knowledge at all, but rather fall out from the basic workings of memory.

THE DISTRIBUTION OF ASSOCIATIONS MODEL. The distribution of associations model (Siegler, 1986; Siegler & Shrager, 1984) illustrates a way in which people could choose strategies effectively without being limited by their explicit knowledge about problem difficulty, cognitive capacities, and the characteristics of different strategies. The model's complexity precludes a full description of it in this context; extensive descriptions of it are available in the above-cited sources. However, the model's main mechanism for choosing between stating a retrieved answer and using a backup strategy is both relatively simple and critical to the present analysis of time-telling. Therefore, we will describe it here in some detail.

The strategy choice involves two interacting parts: a distribution of associations, and a process that operates on the distribution of association to produce behavior. The distribution of associations is made up of associations of varying strengths between particular problems and possible answers to the problem. As an example, the representation of the time when the big hand points to the 6 and the little hand is half way between the 12 and the 1 (12:30) would consist of associations of differing strengths between that configuration of the clock hands and times such as 12:00, 12:30, 1:30, and so on.

The process operates on this representation in the following way. First, the child sets a confidence criterion. This confidence criterion is a threshold that must be exceeded by the associative strength of a retrieved answer for that answer to be stated. It can assume any of a range of numerical values. Once this threshold is set, the child retrieves an answer. The probability of any given answer's being retrieved on a particular retrieval effort is proportional to the associative strength of that answer relative to the associative strengths of all answers to the problem. If the associative strength of whatever answer is retrieved exceeds the confidence criterion, the child states that answer. Otherwise, the child may either again retrieve an answer and see if it exceeds the confidence criterion or abandon efforts to retrieve and instead use a backup strategy to solve the problem.

HOW THE MODEL ACCOUNTS FOR THE DATA. The model accounts for the existence of different strategies, the variability of strategies and particular answers produced by individual children, the particular errors that are made most often, and the relations among percentage of errors, length of solution times, and percentage of backup strategy use. The way in which it does so has been described previously by Siegler and Shrager (1984) for addition, by Siegler (1987b) for subtraction, and by Siegler (1988) for multiplication. Here, the discussion will focus on how the model accounts for when children most frequently use backup strategies.

As noted above, children's pattern of strategy use seems very adaptive. One aspect of this adaptiveness involves when children use each strategy. The more difficult the problem, defined either in terms of high error rates or long solution times, the more often children use the relatively time-consuming backup strategies. In single-digit addition, subtraction, and multiplication, children's frequency of use of backup strategies on each problem has consistently correlated between $r = .75$ and $r = .90$ with the frequency of errors and length of solution times on that problem (Siegler, 1986). This pattern of strategy use is of considerable value to the child. It allows use of retrieval on relatively easy problems, where retrieval is likely to lead to correct answers, yet also leads to use of backup strategies on the
more difficult problems where success would otherwise be unlikely. The pattern cannot be explained in terms of metacognitive knowledge leading to use of the more time consuming backup strategies on the more difficult problems. Siegler and Robinson (1982) found that children’s explicit judgments of the difficulty of each addition problem did not correlate sufficiently highly with the problem’s actual difficulty to allow this route to produce the high correlations that existed between the children’s frequency of use of backup strategies on each problem and the problems’ actual difficulty (with actual difficulty measured by the problem’s mean RT and percent errors).

The distribution of associations model was generated to provide an alternative to metacognitive accounts of strategy choices, one that could produce adaptive choices among strategies even in the absence of explicit metacognitive knowledge. Within the model, the close associations among percentage of errors, length of solution times, and percentage of backup strategy use on each problem arise because all three variables are functions of the same independent variable: the peakedness of the distribution of associations linking a problem to associated answers. To understand the model it is useful to compare its workings on problems where most associative strength is concentrated in the correct answer (a peaked distribution) with its workings on problems where associative strength is distributed among several answers (a flat distribution).

Figure 5.1 depicts a peaked and a flat distribution. When the process operates on these two distributions, its operation on the problem with the peaked distribution (12:00) elicits 1) a higher percentage of retrieval (because the more peaked the distribution, the higher the probability that the answer with greatest associative strength within that distribution will be retrieved and the higher the probability that once the answer is retrieved, its associative strength will exceed the confidence criterion and thus allow the answer to be stated); 2) a higher percentage correct (since the more peaked the distribution, the more likely that the correct answer (the answer at the peak of the distribution) will be retrieved and the more likely that it will be stated if retrieved); and 3) shorter solution times (since the more peaked the distribution, the more likely that an answer whose associative strength exceeds the confidence criterion will be retrieved and stated on an early retrieval attempt). Thus, the model suggests that the reason that use of backup strategies consistently parallels problem difficulty is that the factor that determines percentage of errors and length of solution times, namely the peakedness of distributions, also determines how often backup strategies are used.

The model goes beyond this explanation for the general correlational pattern to predict the types of trials most responsible for the correlations. It indicates that the correlation between percentage of backup strategy use on each problem and percentage of errors on that problem is primarily a correlation between percentage of backup strategy use on each problem and percentage of errors on retrieval trials on that problem. Similarly, the correlation between percentage of backup strategy use on each problem and solution times on that problem should be largely a correlation between percentage of backup strategy use on each problem and solution times on retrieval trials on the problem. As explained above, percent errors on retrieval trials, solution times on retrieval trials, and percent backup strategy use all are hypothesized to be functions of the peakedness of the distribution of associations. In contrast, the model suggests that when children use backup strategies, the peakedness of the distribution does not influence their responses (since at that point, they are no longer trying to retrieve the answer). Errors and solution times on backup strategy trials will be due to specific sources of difficulty that arise in trying to execute those strategies (such as the amount of counting to be done in the counting...
fingers strategy in addition). Because they depend on these specific sources of difficulty in executing the strategy—rather than on the distribution of associations—percentages of errors and lengths of solution times on backup strategy trials on each problem should be less highly correlated with percentage of backup strategy use on that problem.

The patterns of correlations in addition, subtraction, and multiplication all have followed the predictions of the model. Percent errors and length of solution times on retrieval trials on each problem have consistently more closely paralleled percent backup strategy use on that problem than have percent errors and length of solution times on backup strategy trials. The finding is consistent with the view that the children's adaptive patterns of strategy use are byproducts of the workings of the retrieval mechanism. Seen from this perspective, the distribution of associations on each problem determines what is retrieved, and thereby determines patterns of strategy use as well as patterns of errors and solution times. As summarized in Siegler (1986), the present strategy choice model has allowed us to account within a single framework for many additional aspects of children's behavior, including developmental changes in errors, solution times, and strategy use.

The Development of Time-Telling Skills

Surprisingly little is known about how children tell time. Most studies concerned with time have focused on children's understanding of duration (especially speed-distance-time relations), and on their conceptualizations of the various time systems such as the days, months, and years (e.g., Friedman, 1982; 1983; 1986; Levin, 1977; 1979; Levin, Wilkening, & Dembo, 1984; Piaget, 1946/1969, Richards, 1982; Siegler & Richards, 1979). In a society where so much is constrained by the time of day, it is surprising that time-telling is not a more researched domain.

Two initial issues concerning the development of time-telling skills are the ages at which the skills develop and the order in which they are acquired. Several studies have examined the percentage of 4- to 10-year-olds who can state the exact time given particular clock settings. The clock settings can be divided into three, and perhaps four or five, groups. The three clear groups are hour times (e.g., 3:00), 5-minute-times (e.g., 3:25, 3:50), and 1-minute-times (e.g., 3:27, 3:52). Beyond this, it may prove useful to divide 5-minute-times into those that are also quarter and/or half hours (e.g., 3:15, 3:30) and those that are not.

Not surprisingly, the first times that children can tell are typically hour times. Roughly 20% of 4-year-olds, 50% of 5-year-olds, 75% of 6-year-olds, and 100% of 8- and 10-year-olds who have been tested have correctly stated the time for hour settings (Case, Sandieson, & Dennis, 1986; Friedman & Laycock, 1986; Springer, 1952).

With regard to 5-minute-times, Springer (1952) found that fewer than one-third of 5- and 6-year-olds tested could correctly state the exact time for half-hour and quarter-hours. Friedman and Laycock (1986) reported that slightly more than one-third of 6-year-olds and more than 90% of 7-year-olds and older children could solve half hour times. Case et al. (1986) averaged across 5-minute-times and found that 0% of 4- and 6-year-olds, and more than two-thirds of 8-and 10-year-olds could correctly identify 5-minute-times.

Finally, on 1-minute-times, Case et al. reported that 0% of 4- and 6-year-olds, 33% of 8-year-olds, and 70% of 10-year-olds could identify such times correctly. Friedman and Laycock reported somewhat earlier understanding. Like Case, they found that almost none of the 6-year-olds could identify 1-minute-times, but they also found that by age 8, 70% of children could do so.

These observations together tell a fairly clear story about the ages at which middle and late 20th Century North American children can tell various times on analog clocks and the order in which the skills develop. The earliest signs of time-telling ability emerge by 4 years, and the skills are still developing at 10 years. A majority of children appear able to identify hour times by age 6, 5-minute-times by age 7 or 8, and 1-minute-times by ages 8-10. It is possible that half hour and/or quarter hour times can be read earlier than other 5-minute-times. However, because none of the previous studies have systematically compared performance on all of the time settings, it is impossible to reach this precise a conclusion on the basis of the available data.

This limitation notwithstanding, we know a reasonable amount about when children can identify different times and the order in which they learn to do so. However, we know much less about how they decide what time it is and how they make the transition from unskilled to skilled time-telling.

From the perspective of the present model, these issues can be translated into the questions of what strategies children use while they are in the process of learning to tell time and how their choices among these strategies enable them to move from frequent use of backup strategies to consistent use of retrieval. Previous research has established several relevant facts. While children are learning to tell time, they appear to use a number of backup strategies. Four- to 10-year-olds report using such
strategies as counting by 5's from the hour, counting by 5's from prominent reference points such as the half hour, counting backward from the hour, and counting from the nearest 5-minute time (Friedman & Laycock, 1986; Springer, 1982).

The previous research also has established that both adults and children have problem-specific associations between clock settings and verbally-statable times. Paivio (1978) asked adult subjects to determine which of two verbally-described clock settings would have the smallest angular separation between the minute and hour hands of a clock. For example, a subject might be asked "Where would the angle between the clock hands be greater: 1:35 or 12:05?"

The results suggested that subjects possessed specific associations between verbally-stated times and positions of clock hands. The main evidence was the appearance of symbolic distance effects dependent on the physical distance between the clock hands rather than the difference in times. The farther apart the clock hands, the faster the comparison. Thus 11:35 and 12:05 compared more rapidly than 11:35 and 12:35, even though the times were more discrepant in the latter comparison. In addition, subjects verbally reported having used imagery in making their judgements. In other words, adults had associated specific positions of clock hands with verbally described times and used these associations to perform Paivio's task.

Children also seem to associate particular positions of the clock hands with particular times. Both Springer (1982) and Friedman and Laycock (1986) found that when children were asked how they had known it was a given time, they sometimes said that they "just knew" or simply pointed to the hands of the clock. They tended to do this most often on hour-times, next most often on half hour times, and least often on 1-minute times. Further assessing the validity of the verbal reports, the frequency of such retrieval-based descriptions increased substantially with age.

The fact that children learning to tell time possess both backup strategies and problem-specific associations that allow them to retrieve answers suggests that the distribution of associations model may be useful for analyzing their performance. Siegler and Taraban (1986) hypothesized that only two prerequisites have to be met for the strategy choice model to apply to a given task: that the problem-solver have enough experience with the task to have associated specific answers with specific items, and that the problem solver possess one or more backup strategies to use when associative knowledge does not yield an answer on a problem. By this logic, the model should be applicable to time-telling. Further support for this expectation comes from the fact that time-telling has several features in common with the arithmetic domains where the model previously has been found to apply: knowledge of how to tell time is built up over an extended period; it involves both procedures and declarative facts stored in long-term memory; and the direction of change is from greater use of backup strategies to greater use of retrieval.

One feature of time-telling, however, clearly differentiates it from the arithmetic domains: time-telling is a highly perceptual task. None of the numerical domains require the kind of visual information processing that telling time does. One reason for conducting the experiment was to determine whether children's strategy choices in a domain with a large perceptual component would follow the same pattern as has been found in less perceptually-demanding domains.

AN EMPIRICAL STUDY OF CHILDREN'S TIME-TELLING

The main goals of the experiment were:
1. To systematically examine differences among clock times in percent errors, length of solution times, and percent use of backup strategies.
2. To specify the strategies that children learning to tell time use when identifying the time on an analog clock.
3. To assess the temporal and accuracy characteristics of each strategy, and the particular error patterns that each strategy generates.
4. To examine the ability of the distribution of associations model to account for when different strategies are used.

Method

PARTICIPANTS

Second and third graders were chosen for participation, because these were the grade levels at which the children's mathematics text book taught time-telling (and therefore the grades of which children would be in the transition to learning to tell time). The 33 children who participated (9 boys and 9 girls in Grade 2, 5 boys and 10 girls in Grade 3), were students at a middle-class suburban public grade school. The median CA for second graders was 86 mo. (SD=4.5 mo.), and that for third graders was 108 mo. (SD=4.75 mo.). The experimenters were a 31-year-old research assistant and a 21-year-old graduate student (the second author).
STIMULI

Each child was presented one of 3 equivalent sets of 28 clock settings. Each set consisted of all 12 of the 5-minute-times, and 16 of the 48 1-minute-times. Across the three sets, each of the 48 1-minute-times was used once. The 16 1-minute-times within each set consisted of 4 settings where the minute hand was 1 minute past a five mark (e.g. 4:11), 4 where it was 2 minutes past a five mark, 4 where it was 3 minutes past a five mark and 4 where it was 4 minutes past a five mark. For half of the times within each set, the minute hand pointed to a time before the half hour; for the other half, the minute hand pointed to a time after the half hour. The hour settings were chosen randomly, each hour appearing two or three times in each stimulus set. The three stimulus sets are listed in Table 5.1.

Table 5.1
STIMULUS ITEMS FOR THE TIME-TELLING EXPERIMENT

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<thead>
<tr>
<th>SET 1</th>
<th>SET 2</th>
<th>SET 3</th>
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<tbody>
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<td>3:59</td>
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An InterDesign quartz kitchen clock was used to present the times. The clock had a bright yellow frame and a face 7" in diameter. The face was clearly numbered with 1" high numbers (1–12) around the inside circumference. It had dots at each minute mark (with bigger dots at the 5-minute-marks). It also had an opaque removable cover, decorated with cartoon figures, that was used to cover the clock face between trials.

PROCEDURE

Children were presented the 28 times in their stimulus set on two occasions, separated by no more than 3 days. On each occasion, the child was brought individually to a vacant classroom. The experimenter told the child that she would be showing various times on a clock, and that the child's task was to say what the exact time was. Children were also told they could figure out the time in any way they wanted, and that the experimenter would be asking them to describe after each trial how they figured out the time on that trial. The 28 times were then presented in random order.

On each trial, the experimenter set the clock to a given time, placed the cover on the clock face, and then placed the clock in front of the child. The experimenter asked "Can you tell me what time it is now" and removed the cover. After the child answered, the experimenter asked "How did you figure that out?". If the child's answer was too vague (e.g., "I counted"), the experimenter would ask more specific questions such as "Where did you start counting from", or "Show me over again how you counted". After answering, the child was given non-specific reinforcement, and the experimenter proceeded to set the clock to the next time. The entire session was recorded on a videocassette recorder to allow careful analyses of children's strategies on each trial.

The procedure for the second testing occasion was identical except that a different random order of items was used. After completing both sessions, each child was given an explanation of the purpose of the experiment, and was given stickers as a reward for participating.

Results

An overview of the results may be useful for providing a sense of the 8- and 9-year-old's general level of performance. As expected, the children were in the transition between unskilled and skilled time-telling. They correctly identified 69% of the times. Their overall median solution time was 5.8 sec. In terms of both speed and accuracy, hour times were easiest, followed by half hour times, other 5-minute-times, and 1-minute-times. Third graders were slightly more accurate than second graders (70% versus 66% correct) and were considerably faster (mean solution time of 5.1 seconds vs 6.6 seconds). Finally, children generated their responses through use of at least 5 different strategies which produced quite different accuracy and solution time patterns. With these general features esta-
blished, we can consider more specific analyses, first of children's performance on different times, and then of children's strategy use.

PERFORMANCE ON DIFFERENT TIMES

One factor likely to influence children's time-telling was the particular time that they needed to identify. The times can be divided into five groups: hours, half-hours, quarter-hours, other 5-minute-times, and 1-minute-times. One-way, within-subject ANOVAs were conducted to examine differences among these five types of times on three dependent measures: percent correct, median RT, and percent use of retrieval (percent of trials on which children showed no overt behavior between hearing the problem and stating the answer, and on which they said that they just knew the answer or that they remembered it).

PERCENT CORRECT. Percent correct on the five types of times differed significantly, $F(4,160)=23.10, p<.01$. Newman-Keuls post hoc analyses indicated that hour and half-hour times were identified more accurately than quarter-hour and other 5-minute-times, which in turn were identified more accurately than 1 minute-times. Means are shown in Table 5.2.

Table 5.2
PERFORMANCE ON DIFFERENT TYPES OF TIMES

<table>
<thead>
<tr>
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<th>HOUR</th>
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<tr>
<td>MEDIAN RT (SEC.)</td>
<td>3.5</td>
<td>4.1</td>
<td>5.1</td>
<td>5.2</td>
<td>7.4</td>
</tr>
<tr>
<td>PERCENT RETRIEVAL</td>
<td>98</td>
<td>96</td>
<td>80</td>
<td>73</td>
<td>28</td>
</tr>
</tbody>
</table>

SOLUTION TIMES. A parallel ANOVA for median solution time for each subject on each of the five types of times also showed a significant difference among the types of times, $F(4,160)=10.24, P<.01$. The post hoc analyses indicated that hour times were answered more quickly than quarter hour, other 5-minute times, and 1-minute times, and that 1-minute times were answered more slowly than any of the other types of times (Table 5.2).

PERCENT RETRIEVAL. As in the other two ANOVAs, the analysis of percent use of retrieval showed that the five types of times differed signifi-

stantly $F(4,160)=70.63, p<.01$. The post hoc comparisons showed that hour and half hour times elicited a higher percent use of retrieval than did quarter hour times, which elicited a higher percent use of retrieval than did other 5-minute-times, which elicited a much higher percent of retrieval than did the 1-minute-times (Table 5.2).

ADDITIONAL SOURCES OF PROBLEM DIFFICULTY. The ANOVA's indicated that hour and half hour times were easier than other 5-minute-times, and that the other 5-minute-times were easier than the 1-minute-times. We wondered whether further specification of the sources of difficulty within the 5-minute and 1-minute groups was possible. To find out, we identified a number of factors that might predict problem difficulty within the group of 10 5-minute-times other than the hour and half hour and within the group of 48 1-minute-times. These factors were then used as predictors within separate multiple regression analyses of errors and solution times on the 5-minute and 1-minute-times. The predictors within all four regression analyses were number of minutes past the hour (0–59), absolute distance in minutes away from the hour (0–30), number of minutes past the previous quarter-hour mark (0–29), number of minutes before the next quarter-hour mark (0–29), number of minutes past the last 5-minute-mark (0–4), number of minutes before the next 5-minute-mark (0–4), whether the minute hand was before or after the half hour, and whether the time was a 5-minute or a 1-minute time.1

First consider the analyses of the 5-minute-times other than the hour and half hour. In the analysis of median solution time on these trials, three predictors accounted for the large majority of variance: whether the time was before the half hour accounted for 72% of the variance in solution times; number of minutes past the hour brought the total percent variance accounted for to 88%; whether the hour was a quarter hour brought the total variance accounted for to 94%. Times in the first half hour were easier than other times, as were times that were only a short distance past the hour, and times that were quarter hours.

In the analysis of percent errors on the 5-minute-times, whether the time was before the half hour accounted for 66% of the variance; including the time's absolute distance from the hour brought the variance accounted for to 80%. As with the analysis of solution times, whether the time was before the half hour was the best predictor in relative terms and a very good predictor in absolute terms. In this analysis, times that were close to the hour in absolute terms were easier than those that were farther from it.

The analysis of the 1-minute-times yielded less striking results. In the
analyses of median solution times, minutes past the hour accounted for 21% of the variance; minutes past the previous 5-minute-mark brought the variance accounted for to 32%, and minutes away from the nearest quarter hour brought the variance accounted for to 59%. In the analysis of percent errors, absolute distance from the hour was the best predictor, accounting for 14% of the variance; number of minutes past the hour brought the variance accounted for to 26%; number of minutes past the previous 5-minute-mark brought the variance accounted for to 33%. The direction of the effects was the same as in the analyses of 5-minute times.

These analyses of differences in performance on different types of times replicate and extend the findings of Case et al., Friedman and Laycock, and Springer. In general, hour times are easier than half hour times, which are easier than quarter hour and other 5-minute-times, which are easier than 1-minute-times. Whether a time occurs before rather than after the half hour seems to be an additional contributor to the ease of identifying 5-minute-times. Overall, these analyses of performance on different types of times provide an intuitively reasonable description of sources of difficulty in learning to tell time.

On the other hand, examination of the different strategies that children used, and the varying pattern of speed and accuracy on different problems produced by these strategies, indicates that the differences among the types of times just scratch the surface of what is going on in children’s time-telling. For example, across all trials, performance on 1-minute-times is much less accurate than performance on the other 4 types of times, 54% vs 82%. However, all of the difference comes in performance on the 50% of trials on which children used retrieval. On these retrieval trials, children were correct on 88% of 5-minute-times, versus only 29% on 1-minute-times. In contrast, on the 50% of trials where children used a backup strategy, they were actually a little more accurate on the 1-minute-times than on the 5-minute-times, 70% vs 63%. This interaction was not due to different amounts of use of retrieval by second and third graders. Children of both ages were correct much more often on 5-minute trials than on 1-minute trials when they retrieved, and were correct slightly less often on 5-minute trials when they used backup strategies. The point is that only by analyzing the patterns of performance produced by different strategies can the pattern of results be fully understood.

CHILDREN’S STRATEGIES

The children’s overt behavior, together with their self-reports of what they had done, indicated that they used several strategies. Among the most common overt behaviors were sequentially pointing to different places on the clock face, naming aloud sequence of times, and moving lips. When children did not exhibit such overt behavior, or when the meaning of their overt behavior was unclear, we relied on the children’s verbal reports to indicate what strategy they used.

For each of the strategies described below, children first appeared to locate the number that the hour hand had most recently passed, so that they could determine the correct hour. What differentiated the strategies was the children’s subsequent behavior in trying to determine the minutes before or after the hour. More than 98% of trials were classified as involving one of five strategies. The strategies are listed below.

RETRIEVAL. On 50% of trials, children stated the time without any intervening overt behavior and said that they "could just tell" what time it was or that they "knew it just by looking." This approach was classified as retrieval.

COUNTING FORWARD BY 5'S OR BY 5'S AND 1'S FROM THE HOUR. On 14% of trials, children started at the hour and counted by 5’s until they read the 5-minute-mark that the minute hand pointed to (if the time was a 5-minute time), or until they reached the 5-minute-mark immediately before the minute hand, from which point they incremented the count by 1’s until they reached the minute hand.

COUNTING FORWARD BY 1'S FROM THE HOUR. On 2% of trials, children started counting from the hour (e.g. from 3:00), incremented the count by 1’s until they reached the minute hand, and then stated the minutes past the hour.

COUNTING FORWARD FROM AN EARLIER 5-MINUTE-MARK. On 26% of trials, children counted forward from a 5-minute-mark other than the hour. They would say the number of minutes past the hour indicated by their starting position and count-on by 1’s, 5’s, or a combination of the two until they reached the minute hand. This strategy involved a combination of retrieval (of the initial 5-minute-time) and counting. It was used on both 5-minute-times (e.g., 10:25), where a subject might start counting by 5’s from the 15- or 20-minute-mark, and 1-minute-times (e.g., 10:28), where a child might start from the 15- or 20-minute-mark, increment by 5’s until the 25-minute-mark, and then increment by 1’s.

COUNTING BACKWARD FROM A LATER 5-MINUTE-MARK. On
6% of trials, children started counting from a 5-minute-mark that was past the position of the minute hand and decremented by 1’s (or, more rarely, by 5’s or 5’s and 1’s) until the minute hand. For example, if presented 5:38, a child might decrement by 1’s from 5:40.

As these descriptions suggest, children started counting from a variety of places around the clock. The two most prominent landmarks, the hour and half hour, constituted the starting points on 32% and 17% respectively of trials on which children counted. Put another way, children counted from these prominent landmarks on about half of trials on which they counted. On the other half of trials on which children counted, they started from a wide variety of 5-minute-marks. With one exception (the 55-minute-mark), each 5-minute-mark was the starting point on between 4% and 7% of counting trials. The finding indicated that models of time-telling must allow children who are learning to tell time to flexibly begin counting at a variety of marks on the clock face, rather than always needing to start at the hour or half hour.

INDIVIDUAL STRATEGY USE

Variable strategy use was not just a group-level phenomenon. Individual children also used different strategies on different trials. All 33 children used at least three different strategies. Almost three-quarters of the children (73%) used at least three strategies on at least three trials each.

The extreme case of variability in strategy use is use of different strategies by a single child on a single problem presented on two occasions close in time. Even in this extreme case, there was considerable variability in strategy use. Individual children used different strategies on 34% of the pairs of presentations of particular items (the range for individual subjects was 11% to 57% use of different strategies on the two presentations of each time). Learning of the times between the two presentations was not a plausible explanation. First, the two testing sessions were separated by at most 3 days. Second, the direction of change in which strategy was used was inconsistent. In 39% of cases where different strategies were used on the two presentations of a time, the child first used a backup strategy and then retrieval; in 29% of such cases, the child first used retrieval and then a backup strategy; in 32%, the child switched from one backup strategy to another.

This variable strategy use is consistent with the distribution of associations model where, depending on the confidence criterion and the specific answer that is retrieved, any available strategy may be used on any item. It argues against less flexible models that depict children as always using the same strategy to solve a particular problem or class of problems. Further, it is consistent with our general hypothesis that when children have moderate amounts of experience with particular items on a task, they tend to use multiple strategies. Their use of multiple strategies in such situations contrasts sharply with their use of single rules or strategies on unfamiliar problems such as balance scale, projection of shadows, and liquid quantity conservation (Siegel, 1983). It appears that one of the skills that is acquired with experience on a problem is the ability to use multiple alternative strategies.

SOLUTION TIMES AND ACCURACY OF THE STRATEGIES

Table 5.3 indicates the speed and accuracy with which each strategy was executed, as well as how often it was used. To determine the relative speed of each pair of strategies, we compared the mean solution time on each time setting for those trials on which children used one strategy to the mean solution time on that time setting for the trials on which they used the other strategy. Solution times on retrieval trials were significantly faster than those produced by any other strategy, all t’s>2.00, p’s<.05. Solution times were also significantly faster on trials where children counted from an earlier 5-minute-mark or a later 5-minute-mark than on trials where they counted by 5’s or by 5’s and 1’s from the hour.

A surprising feature of the solution times produced by different strategies was that counting by 1’s from the hour was the second fastest strategy. This was largely attributable to the problems on which the strategy was used. The strategy was used almost exclusively on times between 1- and 4-minutes past the hour. Had the strategy been used equally often on different problems, it would probably have been the slowest strategy, since it usually requires the most counting steps. The unequal distribution of use of the strategy indicates the need to consider the problems on which each strategy is used as well as how often each strategy is used in analyzing solution time and accuracy data (Siegel, in press).

The point is equally important in comparing the accuracy of different strategies. Over all trials, the accuracy of retrieval was identical to that of other strategies (69% correct). However, this summary statistic masked great diversity on different problems in the accuracy of retrieval relative to that of other strategies. Retrieval was easily the most accurate strategy on 5-minute-times. However, it was the least accurate strategy on 1-minute-times. Its percent correct was three times as high on the 5-minute-times as on the 1-minute times (Table 5.3). Again, the performance generated by a strategy must be considered in the context of the problems on which the strategy was used.
Table 5.3
CHARACTERISTICS OF TIME-TELLING STRATEGIES

<table>
<thead>
<tr>
<th>STRATEGY</th>
<th>TRIALS ON WHICH STRATEGY USED (%)</th>
<th>MEDIAN SOLUTION TIME (SEC.)</th>
<th>CORRECT ANSWERS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RETRIEVAL</td>
<td>50</td>
<td>4.0</td>
<td>69</td>
</tr>
<tr>
<td>COUNT BY 1'S FROM THE HOUR</td>
<td>2</td>
<td>5.5</td>
<td>86</td>
</tr>
<tr>
<td>COUNT BY 5'S FROM THE HOUR</td>
<td>14</td>
<td>11.1</td>
<td>61</td>
</tr>
<tr>
<td>ALL TIMES</td>
<td>5.8</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>COUNT FROM EARLIER 5-MINUTE MARK</td>
<td>26</td>
<td>7.5</td>
<td>70</td>
</tr>
<tr>
<td>COUNT FROM LATER 5-MINUTE MARK</td>
<td>6</td>
<td>6.8</td>
<td>77</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RETRIEVAL</td>
<td>77</td>
<td>3.8</td>
<td>88</td>
</tr>
<tr>
<td>COUNT BY 1'S FROM THE HOUR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COUNT BY 5'S FROM THE HOUR</td>
<td>12</td>
<td>9.0</td>
<td>70</td>
</tr>
<tr>
<td>5-MINUTE TIMES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COUNT FROM EARLIER 5-MINUTE MARK</td>
<td>8</td>
<td>6.6</td>
<td>61</td>
</tr>
<tr>
<td>COUNT FROM LATER 5-MINUTE MARK</td>
<td>2</td>
<td>6.0</td>
<td>31</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>4.4</td>
<td>82</td>
</tr>
<tr>
<td>RETRIEVAL</td>
<td>29</td>
<td>4.6</td>
<td>29</td>
</tr>
<tr>
<td>COUNT BY 1'S FROM THE HOUR</td>
<td>3</td>
<td>5.5</td>
<td>86</td>
</tr>
<tr>
<td>COUNT BY 5'S FROM THE HOUR</td>
<td>15</td>
<td>12.0</td>
<td>55</td>
</tr>
<tr>
<td>1-MINUTE TIMES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COUNT FROM EARLIER 5-MINUTE MARK</td>
<td>40</td>
<td>7.8</td>
<td>72</td>
</tr>
<tr>
<td>COUNT FROM LATER 5-MINUTE MARK</td>
<td>10</td>
<td>7.0</td>
<td>83</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>7.1</td>
<td>58</td>
</tr>
</tbody>
</table>

PATTERNS OF STRATEGY USE

Some of the strongest predictions of the distributions of associations model concern when different strategies will be used. Specifically, percentage of backup strategy use on a problem is expected to be a better predictor than any structural variable of solution times and errors on that problem, because backup strategy use, like errors and solution time, is a function of the underlying distribution of associations. An even more specific prediction is that the positive relation among percent backup strategy use, percent errors, and length of solution times is primarily a relation among percent backup strategy use, percent errors on retrieval trials, and solution times on retrieval trials. The reason is that errors and solution times on retrieval trials, like percent backup strategy use, are a function of the distribution of associations. In contrast, errors and solution times on backup strategy trials depend on other variables, such as the amount of counting to be done. Thus, percent backup strategy use was expected to correlate highly with percent errors on retrieval trials and solution time on retrieval trials, but not as highly with percent errors and solution times on backup strategy trials.

To test this prediction, several multiple regression analyses were performed. The predictor variables in each one were the same as in the previously-described analyses, except for the addition of one new predictor; percent use of backup strategies on the problem.

RELATIONS BETWEEN BACKUP STRATEGY USE AND SOLUTION TIMES. The distribution of associations model predicts that problems on which backup strategies were used often would also be ones where solution times were long. This proved to be the case. In a stepwise regression analysis of the median RT on each of the 60 times, percent backup strategy use on each problem correlated $r=.76$ with median solution time on each problem. Percent backup strategy use on a problem was the best predictor of solution time on that problem of all the predictors that were examined.

Separate regression analyses of solution times on the 5-minute-times and on the 1-minute-times revealed that the relation between percent backup strategy use and solution time was considerably stronger for the 5-minute than for the 1-minute-times. Specifically, across all 5-minute-times, the correlation between percent backup strategy use and solution time was $r=.92$. On the 1-minute-times, the correlation was $r=.66$. More important, however, for both subsets of items, percent backup strategy use was the best predictor of solution time of the 9 predictors in the regression equation.

This correlation arose at least in part because backup strategies require more time to execute; that is, use of backup strategies causes the longer times. A more specific prediction of the model not subject to this interpretation is that the correlation between percent backup strategy use and length of solution times is primarily a correlation between percent backup strategy use and length of solution times on retrieval trials. This
correlation cannot be attributed to backup strategies requiring more time, because the times in the correlation are times on retrieval trials.

The data were consistent with this prediction. First consider the analysis involving median solution times on retrieval trials. The correlation between solution times on retrieval trials and percent backup strategy use was \( r = .61 \). In contrast, the correlation between percent backup strategy use and solution times on backup strategies was \( r = .14 \). Williams' (1959) modification of Hotelling's (1940) \( t \) statistic showed that the difference between these two correlations was significant, \( Z = 3.02, P < .01 \). Thus, the predictions involving relations between use of backup strategies and lengths of solution times proved accurate.

**RELATIONS BETWEEN BACKUP STRATEGIES USE AND PERCENTAGE OF ERRORS.** The distribution of associations model also predicts that the problems on which backup strategies are used most often will have the highest error rates. Contrary to prediction, the correlation between percentage of errors on the 60 problems and percentage of backup strategy use on these problems was weak and nonsignificant, \( r = .14 \).

Separate analyses of 5-minute and 1-minute-times revealed that this small correlation masked the existence of two larger ones that ran in opposite directions. As expected, on the 5-minute-times, the correlation was fairly strong and positive \( (r = .58) \). Completely contrary to expectation, on the 1-minute-times, the correlation was fairly strong and negative \( (r = -.54) \).

As noted above, if percentage of errors, like percentage of backup strategy use, is a function of the distribution of associations, then the overall correlation between percentage of errors and percentage of backup strategy use should be primarily a function of the percent errors on retrieval trials. The correlation between percent backup strategy use and percentage of errors on retrieval trials was \( r = .36 \). The corresponding correlation for the backup strategy trials was \( r = -.26 \). The difference between these two correlations was significant, \( Z = 3.38, P < .01 \). Again, however, the magnitude of the correlation was lower than expected and lower than correlations between these two variables in previous studies (Siegler, 1987b, 1988; Siegler & Shrager, 1984). A potential reason was suggested by the particular errors that children made.

**ANALYSES OF PARTICULAR ERRORS**

Analyses of children's errors revealed that they were of three primary types: misreading the hour, hour-hand/minute-hand reversals, and off-by-1-minute errors. Together, these three types of errors accounted for 78% of the total errors.

**MISREADING-THE-HOUR ERRORS**

_Misreading-the-hour errors_ accounted for 33% of all errors. This included 28% of errors on retrieval trials and 38% of errors on backup strategy trials. Such misreading-the-hour errors occurred when children identified as the hour the number that the hour hand was closer to, rather than the number preceding the hour hand. This procedure resulted in times such as 3:50 being read as 4:50. As would be expected from this description, such errors occurred exclusively (100%) on times where the minute hand was in the second half of the clock (and therefore where the hour hand was closer to the upcoming hour).

The second frequent error was _reversing the hour and minute hands_. This resulted in times such as 6:05 being read as 1:30. Such reversal errors accounted for 12% of all errors, 14% of errors on retrieval trials and 9% of errors on backup strategy trials.

**OFF-BY-1-MINUTE ERRORS**

_Off-by-1-minute errors_, the third frequent type of error, accounted for 33% of total errors. This included 39% of errors on retrieval trials and 25% on backup strategy trials. It is this type of error that seemed responsible for the surprising relation between the overall percent errors and the percent backup strategy use.

One clue to the pivotal role of this type of error is its different pattern on retrieval trials and backup strategy trials. On 94% of the retrieval trials on which this error occurred, the minute hand was set 1-minute past or 1-minute before a 5-minute-mark. This distribution deviated substantially from chance, \( \chi^2(3) = 100.79, p < .01 \). The error almost invariably (93% of instances) consisted of stating the nearest 5-minute-mark as the time.

In contrast, on backup strategy trials, off-by-1-minute errors were quite evenly distributed across the possible time-settings; 22% were on times that were 1-minute past a 5-mark, 23% were on times that were 2-minutes past, 36% were on times that were 3-minutes past, and 19% were on times that were 4-minutes past. This distribution did not deviate significantly from chance, \( \chi^2(3) = 4.11, p > .10 \).

These differing patterns suggest that off-by-1-minute errors are caused by different processes on retrieval trials than on backup strategy trials. On retrieval trials, but not on backup strategy trials, the errors seem
due to a rounding process in which times within a minute of the nearest 5-minute-mark are rounded to that 5-minute-mark. On backup strategy trials, on the other hand, errors may reflect faulty execution of other processes, such as counting forward and backward.

This rounding interpretation of off-by-1-minute-errors on retrieval trials has several empirical implications. Two have already been noted: the predominance of such errors should (and do) occur on times 1-minute from the nearest 5-minute-mark and the errors should generally be ones of stating the nearest 5-minute time.

Additional implications concern the opposite effects that the rounding process should exert on percent errors on retrieval trials and on percent use of retrieval. The rounding process increases use of retrieval on times 1-minute away from the nearest 5-minute-mark. The reason is that if such a time is interpreted as a 5-minute time, its associative strength will be higher than would otherwise be expected (due to the generally greater amount of experience children have with 5-minute-times). The fact that retrieval was used on 39% of 1-minute-times that were adjacent to a 5-minute-mark, versus 18% of 1-minute-times that were farther away from the nearest 5-minute-mark, supported this prediction.

The other half of the rounding interpretation was that percent errors on retrieval trials should be higher on times that were adjacent to a 5-minute-mark, where rounding would lead to incorrect answers, than on times not so close to the 5-minute-mark, where rounding would rarely be used. This also proved to be true. Percent errors on retrieval trials on times adjacent to a 5-minute-mark was higher than times that were not adjacent to one, 73% versus 67%. In contrast, errors on backup strategy trials did not show this pattern, occurring on 29% of times adjacent to a 5-mark and 31% of times that were farther away.

Together, these results make understandable the initially puzzling weak correlation between percent errors and percent use of backup strategies. Recall that the weak overall correlation subsumed two stronger correlations that went in opposite directions. The correlation for 5-minute-times was in the expected (positive) direction, but the correlation for 1-minute-times was negative. The negative correlation on the 1-minute-times seems attributable to the opposite effects that the rounding process had on errors and strategy use on those 1-minute times that were adjacent to a 5-minute-mark. On such times, rounding would increase percentage of errors on retrieval trials (by leading children to answer with the nearest 5 minute-mark). However, it would decrease percent use of backup strategies (by allowing greater use of retrieval than would otherwise be possible). Thus, both the weak overall correlation between percent errors and percent backup strategy use and the fairly strong negative correlation on 1-minute-times between percent errors and percent backup strategy use appeared to be due to the influence of the rounding process.

**DISCUSSION**

The results of this study allow a fairly detailed depiction of how children make the transition from unskilled to skilled time-telling. They also have implications for the relation of time-telling to other aspects of understanding of time. Below, we summarize our conclusions about children's time-telling, and then go on to speculate about related issues where the present findings are suggestive but not conclusive.

**How Children Learn to Tell Time**

Children's time-telling can be viewed either from the perspective of the times that they tell or from the perspective of the strategies that they use. Previous studies have in large part taken the first perspective, focusing on how children identify different times. Like previous investigators, we found that children learning to tell time were more effective in identifying hour times than other 5-minute-times, and in identifying both of these than in identifying 1-minute-times. The present study also made clear that children identify half hour times almost as effectively as hour times, and considerably more effectively than other 5-minute-times. Further, it showed that within the group of 5-minute-times, times in the first half of the hour are considerably easier than those in the second half. By directly comparing performance on all 60 times on three different measures—percentage of errors, median solution times, and percentage of retrieval—the study allowed more precise identification of differences among the times than previously available.

The main contribution of the study, however, is to illustrate the advantages of also taking the second perspective, and focusing on the strategies that children use to tell time. Clearly, children making the transition to skilled time-telling use a variety of strategies. This is true for individual children as well as across different children. Most individuals used at least three strategies. The children's variable strategy use was evident even within a single clock setting. On one-third of trials, the same child
presented the same clock setting twice within a three day period used different strategies on the two occasions. Thus, strategy use varies within a single child and within a single time, as well as between children and between times.

The distribution of associations model provided a basis for predicting when children would use backup strategies. Basically, the prediction was that they would use backup strategies most often on the problems that elicited the highest percentage of errors and the longest solution times, and that their use of backup strategies would especially closely parallel percentages of errors and lengths of solution times on retrieval trials.

This prediction proved accurate for the relation between use of backup strategies and length of solution times. Across all clock settings, as well as within 5-minute and 1-minute times, percent use of backup strategies was closely related to length of solution times. Also as predicted, the relation was primarily a relation between percent use of backup strategies on the problem and solution times on retrieval trials on it.

The predicted relation between frequency of backup strategies on each problem and frequency of errors on that problem was not found. However, the source of the incorrectness of the prediction was very informative. Examining children's particular errors suggested that a commonly-made error stemmed from a process that would push use of backup strategies and frequency of errors in opposite directions. Specifically, children seemed to round times that were within 1-minute of a 5-minute-mark to that 5-minute-mark. This rounding process increased number of errors on these problems, but also increased use of retrieval rather than a backup strategy. In making these errors, children seemed to be misencoding the 1-minute-time as the nearby 5-minute-time.

It seems, then, that one limiting condition on the generally strong, positive relation between problem difficulty and percent use of backup strategies involves the task's potential for misencoding. If items that have only weakly-associated responses are misencoded as being items with more strongly-associated responses, errors will increase but use of backup strategies will decrease. The opposite effects of such misencoding on errors and use of backup strategies will reduce or eliminate the usual positive correlation between the two variables.

Although the finding may at first seem to undermine the strategy choice model, it also can be seen as demonstrating its strength. Because the model generated clear predictions about the relations among backup strategy use, errors, and solution times, it helped us to detect the anomaly posed by the percentages of errors on different problems not paralleling the patterns of backup strategy use and solution times. Noting this anomaly led to our identifying the three major classes of errors, hypothesizing processes that would generate each type of error and predicting how the process hypothesized to underlie each type of error would affect the overall percentage of errors and percent use of retrieval on each problem. This analysis, in turn, led to our realizing that rounding errors would exert opposite effects on errors and use of backup strategies, and thereby work against the expected correlation. A major purpose of studying time-telling in the context of the strategy choice model was to examine whether the task's relatively strong perceptual recognition component would indicate limiting conditions on generalizations based on children's strategy choices in the previously-studied arithmetic tasks. Discovering how misencoding can differentially affect errors and strategy use was the payoff. We expect that the more precise we can make our models, the more often we will reap such payoffs.

RELATIONS BETWEEN TIME-TELLING AND OTHER ASPECTS OF TIME

Although the present investigation focused on strategy choices in time-telling, the theoretical approach is more generally applicable. Direct evidence for this view comes from a reanalysis of Friedman's (1986 and this volume) data (generously provided by Bill Friedman). These data involved a quite different aspect of children's understanding of time than the one studied here, their representation of the ordering of the days of the week and the months of the year. In the experiment of interest, Friedman asked fourth graders, seventh graders, tenth graders, and college students questions that required knowledge of how far one day of the week or one month of the year was from another. Fourth graders in the study often engaged in overt behaviors in solving these problems (41% of trials); older children and adults occasionally did so (about 4% of trials). More important than the absolute existence of such overt strategies, however, was when the children and adults used the strategies. Percent use of overt strategies was related to percent errors and mean solution times in the ways that the strategy choice model predicts. As shown in Table 5.4, 2 of the 16 correlations among these variables exceeded 60 = 0.60 and 6 of the 16 exceeded 60 = 0.80. All 12 of these relatively strong correlations were in the expected direction. The data are a little noisy, as would be expected given the small number of errors in the older groups and the fact that there were only 6 problems on the days-of-the-week task and 8 problems on the months-of-the-year task. Nonetheless, the overall pattern is clear. Frequency of use of overt strategies closely parallels problem difficulty in identifying the distance between days of the week and months of the year.
as well as in time-telling. The parallel suggests that the way in which children choose strategies is similar across tasks involving quite different aspects of the time concept.

Table 5.4  
CORRELATION OF OVERT STRATEGY USE WITH PROBLEM DIFFICULTY

<table>
<thead>
<tr>
<th>DATA</th>
<th>VARIABLES CORRELATED</th>
<th>GRADE</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4TH</td>
<td>7TH</td>
<td>10TH</td>
</tr>
<tr>
<td>A. WEEKS DATA</td>
<td>% OVERT STRATEGIES - RT</td>
<td>0.89</td>
<td>0.77</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>% OVERT STRATEGIES - % ERRORS</td>
<td>0.27</td>
<td>0.65</td>
<td>0.33</td>
</tr>
<tr>
<td>B. MONTHS DATA</td>
<td>% OVERT STRATEGIES - RT</td>
<td>0.74</td>
<td>0.93</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>% OVERT STRATEGIES - % ERRORS</td>
<td>0.62</td>
<td>0.77</td>
<td>0.57</td>
</tr>
</tbody>
</table>

(Data from Friedman, 1986, Experiment 3)

NOTE: In the weeks task, each correlation is based on the 6 distances between days that were studied. In the months task, each correlation is based on the 8 distances between months that were studied. All correlations are Pearson Product Moment correlations.

What relation might time-telling have to the type of understanding usually viewed as being at the heart of the concept of time, understanding of temporal duration? Speculatively, learning to tell time may directly influence understanding of duration, as measured by performance on the classic Piagetian duration task. This task involves two vehicles moving in the same direction on parallel tracks; problems vary in the relative starting and stopping points, starting and stopping times, and total speed, distance, and time of travel. In trying to solve such problems, children progress through use of different incorrect rules. Five- and 6-year-olds usually use an end-point rule, in which they consistently say that the vehicle that stopped farther down the track traveled for more time (Levin, 1977; Piaget, 1946/1969; Richards, 1982; Siegler & Richards, 1979). In contrast, 8- to 12-year-olds' most common confusion on this problem is to confuse time with distance; they often claim that the vehicle that traveled the greater distance also traveled for the greater time, even when this is not the case (Richards, 1982; Siegler, 1983).

This change from an emphasis on stopping points to an emphasis on total distance improves the children's performance; considering the entire universe of such problems, time is more highly correlated with distance traveled than it is with the end point of travel (Siegler, 1983). However, this view leaves open the question of how children come to confuse time and distance and why the confusion continues for as many years as it does. It clearly is not the case that children of ages 5-12 years lack a concept of duration. The results of Berndt and Wood (1974) and Levin (1977) clearly indicate that they possess such a concept. Nor is it the case that ability to attend to only one dimension when spatial cues are present is the limiting factor. The fact that distance, rather than end points, interferes with their performance indicated that they are attending to both beginning and ending spatial cues.

A quite different interpretation is that learning to tell time on an analog clock contributes to the confusions of time with distance. In particular, learning to tell time may suggest to children that for moving objects, distance traveled and time of travel are related in a 1:1 fashion. Thus, children may rely on distance cues to judge temporal duration on the Piagetian task because they think the two dimensions are perfectly correlated and it is easier to estimate distance than elapsed time.

Several arguments favor this interpretation. Most children receive their first extensive instruction in time-telling at age 8 or 9 (second or third grade), the same age at which children start to confuse time with distance (Siegler & Richards, 1979). On an analog clock, the distance traversed around the circumference stands in a 1:1 relation to the amount of time that has passed; the minute hand's traveling a greater (linear) distance guarantees that a greater amount of time has passed. The relation between time and distance in the context of a clock may be viewed as especially informative, because it is virtually the only situation in which children can be sure of the exact amount of time that has elapsed. Thus, the 1:1 relation on the clock face may be interpreted as representative of a general 1:1 relation between time and distance for moving objects.

Discovering this 1:1 relationship may initially lead children to progress from judging time on the basis of spatial end points on the Piagetian temporal-duration task to the more-often-correct strategy of judging time on the basis of distance traveled. However, it may also be part of the reason that children continue to confuse time with distance for as long as they do. The fact that the object that traveled the longer distance usually is the one that traveled the longer time, together with the 1:1 relation between time and distance in the one situation where children can be sure of the amount of time that has passed, may conspire to make the confusion a difficult one to overcome.

Time-telling may seem like an isolated skill, just one of the thousand-and-one competencies that children acquire at different points in their
lives. Closer analysis, however, reveals interesting relations to processes of considerably more generality. The basic strategy choice procedure that children use while they are in the transition to learning to tell time seems to be the same one that children use while in transitions to acquiring many other competencies. Within the context of the present strategy-choice model, studying time-telling proved to be specially informative, in that it indicated a limiting condition on the model's prediction of high correlations among accuracy, solution times, and strategy use. Specifically, the data on time-telling indicate that perceptual misencodings can push accuracy and strategy use in opposite directions, thus reducing or eliminating the usual correlations among the variables. Thinking about time-telling also has proved fruitful for understanding children's strategies for representing the cyclic structure of days of the week and months of the year and in suggesting an explanation for children's confusion errors on the classic Piagetian duration task. In short, there is more to be learned from studying time-telling than simply when children learn to identify different times.

Acknowledgment

Thanks are due to Miss Hawkins, Miss Perry, and the teachers and students of University Park Elementary School of Monroeville, PA, who made the research possible.

Notes

1The reason that the time to or past the quarter hour ranged from 0–29 minutes was that the only times in this analysis that were quarter hours were those that were 15 and 45 minutes past the hour.

References


CHAPTER 6

Assessing Children's Understanding of Time, Speed and Distance Interrelations

INTRODUCTION

Piaget (1969; 1970) set the stage for the investigation of children's understanding of time, speed and distance interrelations by insisting that a mature concept of time emerges during middle childhood and is built upon an understanding of the interrelations between the three dimensions. He was struck by the fact that young children's reconstruction of temporal events and their judgments of relative durations are not based on direct perception of start and stop times but rather on intuitive suppositions concerning the dependence of time on speed and on distance. These confusions eventually disappear, and Piaget argued that this comes about only when children replace their intuitive suppositions with an accurate representation of the interrelations between all three dimensions. Thus, from Piaget's point of view, the development of children's understanding of time, speed and distance interrelations was seen as the cornerstone of the development of the time concept.

Piaget's theory of the development of the time concept is reminiscent of his argument concerning the development of conservation, and the same