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Development of Time, Speed, and Distance Concepts

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The rule-assessment approach was used to examine 5-, 8-, 11-, and 20-year-olds' understanding of the concepts of time, speed, and distance. Parallel tasks were developed for the three concepts that allowed specification of whether children were relying on time, speed, distance, end point, end time, beginning point, or beginning time cues in making their judgments. It was found that 5-year-olds understood all three concepts in the same way: Whichever train ended farther ahead on the tracks was said to have traveled for the longer time, at the faster speed, and for the greater distance. Twenty-year-olds, at the other extreme, understood all three concepts as distinct and separate ideas. The transitional period was marked by specific confusions among the three concepts: Time was regularly confused with distance, distance was confused with time, and speed was confused with distance and to some extent with end point. Both speed and distance concepts appeared to be mastered well before the concept of time.

In 1928, Albert Einstein posed a question to Jean Piaget: In what order do children acquire the concepts of time and speed? The question was prompted by an issue within physics. Newtonian mechanics viewed time as a fundamental notion and defined speed in terms of it (velocity = distance/time). Relativity theory, by contrast, defined time and speed in terms of each other (and in relation to fixed points), with neither concept viewed as the more basic. Einstein wanted to know which concept children understood first, whether understanding of each was intuitive or derived, and how initial understanding of one concept influenced subsequent understanding of the other.

Almost 20 years later, Piaget published a two-volume, 500-page reply to Einstein's query (Piaget, 1946a/1969; 1946b/1970). The evolution of the concepts of speed and absolute linear time had proved to be considerably more complex than the original question suggested. Contrary to the assumption of Newtonian mechanics (and Kantian philosophy), neither time nor speed seemed to constitute a priori ideas for young children. Instead, each of them, along with the concept of distance, appeared to undergo a three-stage developmental progression. In Stage I, children were said to define time, speed, and distance concepts solely in terms of the spatial stopping points of objects; for example, if two toy trains traveled on parallel tracks, whichever one stopped at the point farther ahead was said to have traveled for a longer time, at a higher speed, and for a greater distance. These children were generally 4- and 5-year-olds, clearly in the preoperational stage. Piaget (1970) said of them: "At first, the general question of the placing of the stopping points seems to dominate every judgment" (p. 181). In Stage II, children were said to begin to consider other factors, such as the starting points of the trains. Piaget (1970) commented about them: "In short, during this stage there is progressive decentration of intuition fixed on the stopping point" (p. 190). Finally, around age 7 or 8, children were said to enter Stage III, the stage of mastery. In Piaget's (1970) words,

"around seven or eight years, three correlated constructions are observed: temporal order is dissociated

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from succession in space, distances travelled are conceived as lengths occupying the interval between the *given starting and stopping points, and in the case of* synchronous movements, speed is defined in terms of those lengths covered in equal times" (pp. 190–191).

Not coincidentally, 7 or 8 years is the age at which Piaget says children generally enter the stage of concrete operations.

There appear to be a number of reasons for questioning this account, however. One is that the account is inconsistently rendered; for example, in some passages, 5-year-olds are said to confuse time with spatial end points (e.g., Piaget, 1970, p. 181), whereas in others they are said to confuse time with total distance (e.g., Piaget, 1969, p. 111). Another problem is methodological; despite claims that all three concepts are mastered simultaneously, Piaget never appears to have examined the same children on all three tasks. An additional methodological problem is that the tasks that were used to assess understanding of the three concepts were not entirely comparable; there were numerous differences in the materials used, the questions asked, and the particulars of the procedures. Finally, Piaget's account of the intermediate period (Stage II) is vague, with only a sketchy picture of the transition process emerging.

Surprisingly little subsequent research has been conducted on the development of the time, speed, and distance concepts. All but one of the published studies that we were able to locate examined only the concept of time. (Among these studies were Berndt & Wood, 1974; Friedman, 1978; and Levin, 1977; the exception was Weinreb & Brainerd, 1975, who examined both speed and time.) None of these studies focused on the sequence of strategies leading to full understanding of any one of the concepts or on the order of mastery of the three of them.

The present study was intended to add to research on time, speed, and distance concepts in two ways: by determining the sequence of knowledge states leading to mastery of each of the three concepts and by specifying the order in which the three concepts are understood. To achieve these goals, it was necessary to overcome some of the methodological limitations of Piaget's (1969, 1970) experiments. First, a task was created that would allow comparable assessment of the understanding of time, speed, and distance concepts. Children were shown two parallel train tracks with a locomotive on each of them. The two locomotives could start from the same or different points, could stop at the same or different points, and could go the same or different distances. They could start at the same or different times, could stop at the same or different times, and could travel for the same or different total time. Finally, they could go at the same or different speeds. Within this situation, children could be presented completely parallel speed, time, and distance problems. They would see the train go for a particular distance, at a particular speed, and for a particular time, and then they would be asked, "Which train went (for the longer distance) (faster) (for the longer time)?" This allowed direct comparison of the understanding of the three concepts.

The next step was to find a method for objectively assessing children's knowledge of time, speed, and distance concepts. The rule-assessment methodology seemed likely to be useful for this purpose. This approach involves formulating models of rules that children might use to perform various tasks and then formulating different types of problems that allow discrimination among the rules. Its virtues are that it is both revealing and reliable; it has proved able to reveal the strategies that children of different ages use to solve a variety of concrete and formal operations problems (Klahr & Siegler, 1978; Siegler, 1976, 1978a, 1978b; Siegler & Vago, 1978; Siegler, Note 1) while at the same time allowing perfectly reliable scoring due to its reliance on simple, nonverbal responses as the basic data (cf. Siegler, 1978a for an extended discussion of the methodology).

The first step in using the rule-assessment methodology was to formulate models of the rules that children might use to perform the three tasks. Based on Piaget's initial investigations, three rule models were proposed. Children using Rule I would judge solely on the relative stopping points of the trains. If one train was ahead, that train would be said to have traveled farther, faster, and for a longer time; if the two trains stopped in the same position, they would be said to have traveled for an equal time, distance, or speed. Those using Rule II would perform similarly if one train stopped ahead of the other, but if the two trains stopped equally far down the tracks, they would choose the train that started from farther back. Finally, those using Rule III would solve all problems correctly regardless of the positions of the stopping points. Many possible variants of these rules were possible—for example, children at some point might always rely on total distance to estimate time or might rely exclusively on beginning rather than ending point to estimate distance—but Piaget's descriptions did not allow any more precise advance specification. As will be seen, an advantage of the rule-assessment methodology is that it allows us to determine children's knowledge states even if the initially hypothesized rules turn out to be incorrect.

The next step was to design problems for assessing whether children actually used these or other rules. The six types of problems that were chosen are shown in Table 1. These problem-types allow discrimination among rules corresponding to the seven physical dimensions along which the trains could differ: time, speed, distance, end point, end time, beginning point, and beginning time. A child responding on the basis of any of the seven dimensions would answer differently on at least two of the six problem-types from a child responding on the basis of any other dimension. (It should be noted that the differences between some problem-types, e.g., 4 and 5, were designed expressly to allow discrimination among rules corresponding to these seven physical dimensions rather than just among the three hypothesized rules for each concept.) In addition, the problem-types were chosen to limit the difficulty of the task in several ways. Total time, total distance, and average speed were never equal for the two trains; even adults have great difficulty judging whether two trains that did not start and stop at the same time travelled at exactly the same speed or for the same amount of time (Fraisse, 1963). The problems were also designed so that the trains either started at the same time or finished at the same time; again, research with adults indicates that even they have difficulty making temporal judgments when neither starting nor ending times are equal (Fraisse, 1963).

Pilot tests revealed that such speed, time, and distance concept problems may not be fully mastered until ages considerably later than Piaget suggested. Therefore, in the present experiment, the problems were presented to people of a wide age range: 5-year-olds, 8-year-olds, 11-year-olds, and adults. The primary goals were to determine the order of mastery of the three concepts and to establish the developmental sequence of knowledge states leading to mastery of each of them.

Method

Participants

Thirty-six children attending an upper-middle class suburban school and 12 undergraduate college students served as subjects. The children included 12 kindergarteners [mean chronological age (*M* CA) = 68 months, *SD* = 3.4], 12 third graders (*M* CA = 104 months, *SD* = 4.3), and 12 sixth graders, (*M* CA = 141 months, *SD* = 4.2). The college students were predominantly freshmen and sophomores in an introductory psychology course. One half of the individuals in each group were male and one half were female. There were two experimenters: a 22-year-old white female research assistant and a 22-year-old white male graduate student (the second author). Both experimenters worked with each subject as will be indicated later.

Materials

Materials included two HO-gauge locomotives (one blue and one red), two 3-m lengths of track, two transformers, and three identical Hunter timers. Two of the timers served as duration timers; they controlled the number of seconds that the trains would travel. The third timer served as the delay timer; it could impose a delay between the time when the first and the second trains started. Each track had its own transformer, thus allowing independent control of the speeds at which each locomotive would travel. The combined control of time and speed allowed control of the distances the trains would go as well. Due to the nature of electric trains, this control was not perfect, however. On trials when the trains were to stop at the identical points, it was necessary to put small pins at the intended stopping points so that the stopping points would in fact be identical. The trains were moving slowly enough by the time they reached the barriers that the prematurity of their stops was barely noticeable.

Table 1
Specific Response and Percentage of Correct Answers Predicted by Each Rule for Each Problem Type on Time, Distance, and Speed Concepts

	Problem-type[a]					
Train	1	2	3	4	5	6
A	0____6	0____9	0___9	0__6	0____6	0___5
B	2____6	0__5	4½____9	0__5	0__4	2__5
			Time concept			
Rule I	A longer	Equal	A longer	B longer	A longer	B longer
%[b]	100	0	100	0	100	0
Rule II	A longer	A longer	A longer	B longer	A longer	B longer
%	100	100	100	0	100	0
Rule III	A longer	A longer	A longer	A longer	A longer	A longer
%	100	100	100	100	100	100
			Distance concept			
Rule I	A longer	Equal	A longer	B longer	A longer	B longer
%	100	0	0	100	100	0
Rule II	A longer	A longer	A longer	B longer	A longer	B longer
%	100	100	0	100	100	0
Rule III	A longer	A longer	B longer	B longer	A longer	A longer
%	100	100	100	100	100	100
			Speed concept			
Rule I	A faster	Equal	A faster	B faster	A faster	B faster
%	0	0	0	100	100	0
Rule II	A faster	B faster	A faster	B faster	A faster	B faster
%	0	100	0	100	100	0
Rule III	B faster	B faster	B faster	B faster	A faster	A faster
%	100	100	100	100	100	100

[a] Numbers in the problems correspond to the number of seconds since the beginning of the trial. Lengths and relative positions of lines correspond to distances traveled and spatial positions. Thus, in the example in Problem-type 1, one train (A) would start at the beginning of the trial and travel for 6 sec, whereas the other (B) would start 2 sec after the trial began and would also stop at 6 sec. The two trains would start from parallel points, but Train A would finish farther up the track.
[b] Predicted percentage of correct answers.

Test Problems

For each concept, children were presented a set of 24 items, 4 items each of the six problem-types shown at the top of Table 1. The 24 items were identical across the three concepts in terms of the trains' activities; all that differed was whether the question that was asked concerned speed, time, or distance. Items were ordered within the sets by means of a stratified random-sampling procedure so that 1 item of each problem-type was in the first six, one was in the second 6, and so on.

The pattern of responses that would be generated by children following the proposed Rules I, II, and III can be compared for the three concepts in Table 1. As shown, children using Rule I on all three concepts would always solve Problem-types 1, 3, and 5 on the time concept; 1, 4, and 5 on the distance concept; and 4 and 5 on the speed concept. They would always err on Problem-types 2, 4, and 6 on the time concept; 2, 3, and 6 on the distance concept; and 1, 2, 3, and 6 on the speed concept. Similar comparisons can be made for the other two hypothesized rules and for the remaining unhypothesized rules as well.

Individual items were designed so that a child attempting to use any particular rule would not have to make very difficult discriminations. For some rules, this did not necessitate any special arrangements. It would be easy for children who judged on the basis of the end points, beginning points, end times, or beginning times to tell which train was greater on that dimension. Judging total time, total distance, and average speed, however, seemed likely to be more difficult. Therefore, the items were tailored to minimize difficulties of judgment on these dimensions. The train that went faster always went at least 6 cm/sec faster, the train that went farther always went at least 13 cm farther, and the train that went the longer time would always go for at least 2 sec longer. In relative terms, the two trains' times, speeds, and distances always differed by at least 33%. Pilot data indicated that this arrangement accomplished its goal: Adult subjects, who presumably understood the concepts, were easily able to judge which train went farther, faster, or for a longer time.

Rule Assessments

The same criteria for rule usage were followed as in previous studies using the rule-assessment approach (Siegler, 1976, 1978a, 1978b; Siegler & Vago, 1978). For a child to be classified as using a rule, at least 20 of the child's 24 responses needed to be predicted by that rule. Since there were 3 possible responses on each item (Train A is greater, Train B is greater, they are equal), this meant that the rule models needed to predict not only which items would be solved correctly and which would produce errors but also the particular errors that would be made. Such a criterion made it very unlikely that random responders would be said to be using a rule.

Also, as in the previous studies, two additional criteria were used to insure that children who were classified as using one rule were not in fact using a different rule. One of these criteria involved discrimination between Rules I and II. Only Problem-type 2 yielded different answers for children using the two formulas. Therefore, to minimize erroneous classifications, a child was required to answer at least three of the four three-choice items on this problem-type in accord with a rule to be classified as using that rule. If this criterion was not met (e.g., if the child made one response in accord with Rule I, two in accord with Rule II, and one in accord with neither rule), the child was classified as not having used any rule. Second, in several cases only two problem-types discriminated among rules; here, children were required to answer six of the eight discriminating items in accord with one rule or the other. Past use of these criteria has demonstrated that they yield the same rule classifications for more than 80% of children across a 1-month period, an indication of the classifications' stability (Siegler, 1978b; Siegler, Note 1).

If at the end of the predictions set a child's performance did not appear to meet the hypothesized Rule I, II, or III criteria, the experimenters would recreate one Problem-type 4 and one Problem-type 2 item and ask on each of them, "How did you know which train went the (longer time) (longer distance) (faster speed)?" Children's explanations were tape recorded and later transcribed. The main purpose of this procedure was to provide converging evidence for any patterns that might later emerge when the predictions were scrutinized more carefully. Reliability in scoring the explanations proved relatively easy to obtain; among the 57 instances in which the experimenter requested explanations (including cases where the children's performance proved to meet the rule criteria), all three raters agreed in 49 cases (86%).

Procedure

Each child was brought individually to the experimental room, a vacant classroom within his or her school, on 3 different days within a 1-week period. When the child arrived, he or she was led to a seat from which both trains could be viewed clearly. The following instructions were then given:

> Today we are going to play a game with these trains. Each train has its own track and can go up and down it. Now the way we play the game is this; we're going to start these trains and they will go down the tracks for a while and then stop. I want you to watch the trains closely and then tell me which train goes (for a longer time) (a longer distance) (a faster speed). I want you to tell me if the red train goes (for a longer time) (a longer distance) (a faster speed) or if the blue train goes the (longer time) (longer distance) (faster speed) or if they go the same (amount of time) (distance) (speed).

One practice trial was presented, followed by the 24 test items for that concept. Before each item, the child was told to watch whether the trains went the same or different times, speeds, or distances. One experimenter positioned the trains and set the two transformers while the other set the three timers and recorded the child's responses. Order of presentation was counterbalanced across concepts, so that one third of the children in each grade were assessed on speed first, one third on time first, one third on distance first, and so on. Each session took between 15 and 25 minutes.

The procedure that was followed with adults differed in two ways. They were run in groups of three to six people, rather than individually, and they recorded their own responses rather than having the experimenter do so. Otherwise, the procedure was identical.

Results

Separate Age × Problem-type × Sex of Subject × Order of Presentation (4 × 6 × 2 × 3) analyses of variance for each concept revealed that there were no significant effects for sex or order of presentation on any of the three concepts. In addition, neither of these variables interacted with age or problem-type. Therefore, no further consideration will be given to them.

Contrary to expectation, children who

were classified as using Rule II did not choose on the basis of beginning point when the end points were equal. Instead, when the end points were equal, these children consistently chose the train that stopped sooner; all 16 Rule II protocols reflected this pattern in terms of the previously described criteria of Rule II predicting at least 20 of 24 total responses and at least 3 of the 4 responses on Problem-type 2. Children who were classified as using Rule II also were quite explicit in verbalizing this rationale; 13 of the 16 children's explanations were assessed as reflecting this approach by all three raters who examined them. In addition, the children who used the approach tended to use it very consistently; for example, 3 kindergarteners used it on all three concepts. All subsequent references to the predictions of Rule II are therefore derived from this formula rather than from the one originally proposed.[1]

Distance Concept

Among the 48 subjects, 41 could be classified as using a rule on the distance-concept problems. As shown in Table 2 (distance concept), 15 used the hypothesized Rule I in which they judged distance solely on the basis of the stopping points of the trains, 4 used Rule II in which they also considered stopping time when the stopping points were equal, and 22 used Rule III in which they consistently answered the distance problems in terms of the relative distances. The performance of the other 7 subjects seemed to most closely approximate Rule III but fell short of meeting the criterion of 20 of 24 correct answers.

Rule usage was strongly related to age. Five-year-olds predominantly used Rules I and II; 8-year-olds most often used Rule I and sometimes used Rule III, 11-year-olds sometimes used Rule I and most often used Rule III; and adults always used Rule III. The implications of this shift in rule usage for the pattern of correct answers and errors can be seen in Table 3 (distance concept). On the problem-types (1, 4, and 5) that Rules I and II would solve, performance was consistently high from age 5 onward. On those that only Rule III would solve (Types 2, 3, and 6), 5-year-olds performed consistently below chance and even 11-year-olds often erred.

Table 2
Number of Children Using Each Rule

Age group	Rule used				
	I	II[a]	Distance	III	No rule
	Distance concept				
5–6	6	4	0	0	2
8–9	6	0	0	3	3
11–12	3	0	0	7	2
Adult	0	0	0	12	0
	Speed concept				
5–6	6	6	0	0	0
8–9	1	0	0	4	7
11–12	0	0	0	10	2
Adult	0	0	0	11	1
	Time concept				
5–6[b]	6	4	0	0	1
8–9	1	2	0	0	9
11–12	0	0	5	2	5
Adult	0	0	0	11	1

[a] The numbers of children using Rule II refer to the revised Rule II in which children judge on the basis of stopping times when end points are equal.
[b] One child used the speed rule on the time concept.

Speed Concept

Thirty-eight of the 48 children and adults could be classified as using a rule on the speed-concept problems (Table 2). Seven used Rule I, in which they judged speed on the basis of the stopping points of the trains; 6 used Rule II, in which they chose the first train to stop when the stopping points were equal and relied on end points when they were unequal; and 25 used Rule

[1] It should be noted that there was another interpretation of the Rule II protocols that was equally consistent with the predictions data; that is, when end points were equal, the children chose the train that had traveled faster. As noted above, the explanations data were much more consistent with the alternative view that these children relied on end time when end points were equal. Nonetheless, it would be desirable to differentiate between the interpretations further by presenting children new problem sets including more than one type of equal end point problem.

Table 3
Percentage of Correct Answers on Each Problem Type

Age group	Problem type 1	2	3	4	5	6
	Distance concept					
5–6	81	21	21	83	90	15
8–9	96	40	40	79	98	50
11–12	96	67	60	71	100	77
Adult	98	94	98	92	100	100
	Speed concept					
5–6	2	46	6	98	100	10
8–9	56	58	73	96	98	81
11–12	58	81	88	98	98	94
Adult	79	85	96	100	92	92
	Time concept					
5–6	77	21	71	10	90	21
8–9	90	60	58	38	94	73
11–12	88	94	27	58	92	92
Adult	92	96	81	81	100	100

III, in which their answers were consistently correct. As on the distance concept, children who were not classified as using any rule most often appeared to be trying with mixed success to use Rule III; not surprisingly from this perspective, most of them were concentrated in the age group just prior to the one in which use of Rule III became general.

As shown in Table 2 (speed concept), there was again a clear relationship between children's ages and the types of rules they used. Five-year-olds were divided evenly between use of Rule I and use of Rule II. Eight-year-olds were divided evenly between use of Rule III and use of no classifiable rule. Eleven-year-olds and adults consistently used Rule III. This pattern of rule usage allowed explanation of the correct answer and error data found in Table 3 (speed concept). On Problem-types 4 and 5—the problem-types that both Rule I and Rule II would solve—performance was very accurate from age 5 onward. On Problem-type 2—which Rule II but not Rule I would solve—performance progressed from a moderately high level at age 5 to consistently correct responding at later ages. Finally, on Problem-types 1, 3, and 6—which neither Rule I nor Rule II would solve—performance progressed from well below chance at age 5 to consistently correct performance by age 11.

Time Concept

The time-concept data yielded in many ways the most interesting of the three developmental sequences. Thirty-two of the 48 subjects could be classified as using rules. Seven consistently indicated that the train that stopped farther ahead had traveled for the longer time (Rule I); 6 relied on end points in making their judgment unless the end points were equal, in which case they chose the first train to stop (Rule II); 5 regularly indicated that the train that traveled the greater total distance had gone for the longer time (the distance rule); and 13 used the correct time rule (Rule III).[2] Again, there was a clear relationship between the rules children used and their ages (Table 2; time concept). Five-year-olds most often used Rule I or Rule II, 8-year-olds generally did not use any classifiable rule, 11-year-olds either used the distance rule or no classifiable formula, and adults almost always used Rule III. The implications of these statements for children's pattern of correct answers and errors are illustrated in Table 3 (time concept). Five-year-olds consistently solved those problems that Rules I and II would solve—1, 3, and 5—and performed well below chance on those they would not solve—2, 4, and 6. By age 11, a large shift had occurred; now, children did very well on those problem-types that the distance rule would solve—1, 2, 5, and 6—but they did far less well on those problem-types for which the distance rule would fail—3 and 4. The large developmental decrement on Problem-type 3, which the end point rule would solve but the distance rule would not, is especially striking (Table 3; time concept). Finally, by adulthood, all of

[2] In making the rule assessments, raters examined the fit of the child's performance to each of the seven physical dimensions along which problems varied, not just the three hypothesized rules. This led to discovery of the distance rule.

the types of problems were generally answered correctly.

Consistency of Reasoning on the Three Concepts

The youngest and oldest subjects in this study showed considerable consistency in their level of reasoning across the three concepts. Among the 5-year-olds, this consistency took the form of equating each concept with the spatial stopping points of the trains, especially when the stopping points were unequal. Six of the 10 kindergarteners who could be classified as using any rule on all three concepts used the same rule on each of them. Adults were consistent in a different way. They possessed fully differentiated understandings of the three concepts. Eleven of the 12 adults met the standards for using Rule III on all three concepts, and the one who did not use it on all three used it on one of the three and missed by only one response on the other two.

Unlike 5-year-olds and adults, 8- and 11-year-olds did not usually use the same type of rule on all three concepts. Rather, their pattern of responses indicated that they mastered both speed and distance concepts long before they mastered the time concept. This trend was apparent in the number of 8- and 11-year-olds using Rule III on each concept: 14 used it on the speed problems, 10 used it on the distance problems, and only 2 used it on the time problems. Among the 14 children who used Rule III on either the speed or time problems but not both, 13 used it on speed, only 1 on time ($p < .001$, Fisher's sign test; cf. Hollander & Wolfe, 1973). Among the 8 children who used it on distance or time but not both, all 8 used it on distance ($p < .005$). Finally, among the 8 who used Rule III on either speed or distance but not both, 6 used it on speed versus 2 on distance ($p < .15$). These analyses clearly indicate that both speed and distance concepts are mastered before time and suggest that speed is either mastered slightly before distance or concurrently with it.

Non-Rule-Governed Performance

As mentioned earlier, some subjects did not meet the criteria for using any of the rules: 16 on the time concept, 10 on the speed concept, and 7 on the distance concept. Examination of these subjects' responses revealed a distinctly nonrandom pattern of correct answers and errors on all three concepts. To clarify the approaches that they were taking, multiple regression analyses were performed for each task. The dependent variable was the number of errors made on each of the 24 test items by "no rule" subjects. The predictor variables were total time, total distance, average speed, end point, end time, beginning point, and beginning time. All predictors except the conceptual variable itself were treated as dichotomous, with their scoring depending on whether they pointed toward the right answer or away from it. Thus, in Problem-type 1 on the time concept (Table 1), distance, end point, and beginning time were assigned scores of 1, whereas speed, beginning point, and ending time were assigned scores of 0. Such treatment was not possible for the conceptual variable itself, since by definition it always pointed toward the correct answer. Instead, because it was possible that the degree of disparity on the conceptual variable was important (e.g., children might have had difficulty judging the greater time when the two choices were relatively close on the time dimension), the 24 items were represented as ratios of the larger to the smaller value and the conceptual variable in each analysis was treated as continuous.

The results of the regression analyses indicated that it was possible to account for most of the errors that were made by no-rule subjects with a very small number of predictor variables. On the time concept, 67% of the total variance could be accounted for in terms of the distance variable's status, $F(1, 22) = 43.78; p < .001$; errors generally occurred when the train that traveled the longer time did not go the longer distance. None of the other factors added as much as 5% to the percentage of variance that could be accounted for. Conversely, on the distance concept, the largest part of the total variance (38%) was accounted for by the status of the time variable, $F(1, 22) = 21.95$, $p < .001$. Once again, the problem-types in which time and distance pointed in opposite directions caused the greatest difficulty.

In addition, the speed variable and the distance ratios added significant amounts when combined with time, $F(1, 20) = 4.48$, $p < .05$, and $F(1, 20) = 4.44$, $p < .05$, respectively; the three variables together accounting for 60% of the variance on distance errors. Finally, on the speed concept, the distance variable was the single most important, accounting for 60% of the variance $F(1, 21) = 60.14$, $p < .001$, but the end point cue added significant variance, $F(1, 21) = 11.25$, $p < .01$; the two variables together accounting for 74% of the total variance.

Regression analyses were also run on the errors made by subjects who used Rule III. These analyses yielded a pattern of results similar to that of the no-rule subjects. For example, on the time concept, the distance variable accounted for the most variance; on the distance concept, the time variable accounted for the most variance; and on the speed concept, the distance variable accounted for the most variance. This finding, that the sources of errors were the same for no-rule and Rule III subjects, was consistent with the view that the no-rule subjects were trying to use Rule III but were not very adept at it. That 20 of the 33 unclassifiable protocols missed being classified as Rule III by only one or two responses also was consistent with this interpretation.

Discussion

Two questions were posed at the outset of this study: What are the knowledge states leading to understanding of time, of speed, and of distance? and, In what order are the three concepts mastered? The experimental results added substantially to our understanding of both of these issues.

With regard to the first question, most of the results concerning initial and final knowledge states were in agreement with Piaget's (1969, 1970) previous observations. In the beginning, children relied heavily on the Rule I approach; time, speed, and distance were all equated by 5-year-olds with the relative stopping points of the trains. In the end, each concept was understood as a distinct entity, separate from the others; adults almost exclusively used the Rule III approach on all concepts. The only major departure from Piaget's findings regarding the initial and final knowledge states concerned the age at which Rule III was attained; time and to some extent distance seemed to be mastered at much later ages than Piaget claimed. (For similar previous findings regarding the age of mastery of the time concept, see Weinreb & Brainerd, 1975.)

The findings regarding the transition period were less directly supportive of Piaget's account, however. The rule that seemed to us to correspond most closely to Piaget's description of the transition period (the original Rule II) did not appear at all, and the variant of Rule II that did appear was used predominantly at very young ages, long before any of the concepts were mastered. Instead, the direct predecessors of Rule III appeared to be knowledge states in which the concepts were partially understood but still partially confusable with each other. These knowledge states were in general ways compatible with Piaget's descriptions, but the rule assessments and regression analyses allowed much closer specification of what the children actually did. This was the case for all three concepts but in somewhat different ways for each of them.

On the time concept, the state before full mastery seemed to be one in which time and distance were only partially differentiated. This was evident in the use of the distance rule to judge time by a large number of 11-year-olds. It was also evident in the results of the regression analysis of the errors of children who could not be classified as using any rule. Yet a third source of evidence was the large developmental decrement from age 5 to age 11 on Problem-type 3—the only problem-type solvable by the end point rule but not by the distance one. Five-year-olds solved 71% of these problems, 11-year-olds solved only 27%.

There was a similar confusion between time and distance when children were asked to judge which train went the longer distance. This confusion did not lead to any children using a strict time criterion to judge distance. It did show up in the regression analyses, however, indicating that the most difficult items were those on which the train that traveled the longer distance traveled the shorter time. It was also evident in the one developmental decrement in judgments of distance—Problem-type 4—which was the only problem type on which end point pointed to the correct answer and time to the wrong one.

Finally, on the speed concept, it seemed that distance was the largest source of confusion and that end point was also important. This was reflected most directly in the regression analysis; it was also evident in the percentage of correct answer data (Table 3; speed concept) showing that the problem types in which distance and end point pointed in the opposite direction from speed (1 and 2) were far more difficult than any of the others. Similarly, the lack of any developmental decrements on the speed concept can be attributed to there being no problem-types in which Rule I suggested the correct answer and distance the wrong one.

The concepts differed substantially in the ages at which children attained Rule III. A number of children mastered both speed and distance concepts by age 8, and the majority mastered them by age 11. In contrast, Rule III on the time concept was rarely attained by either 8- or 11-year-olds; only adults used it extensively. This relatively late mastery (somewhere between age 11 and adulthood) did not seem directly attributable to the particular time problems being unusually difficult. Recall that the trains always either stopped at the same time or started at the same time (Table 1); this created a situation in which the child could simply reason that since A and B started simultaneously and A stopped later than B, A must have traveled for the longer time. It was also the case that the times of travel of the two trains always differed by at least 33% and by at least 2 sec. Finally, although the ratios of the two times varied from 1.33:1 to 3:1, the regression analyses revealed no effect of this variable. Thus, it seems that the apparent lateness of the development of full understanding of time cannot be explained in terms of the present test items being particularly difficult; rather, it seems that children do not fully grasp the time concept until late in development.

In light of these findings, it seems worthwhile to return to Einstein's original question of a half-century ago. Part of the answer to this question now seems clear. Children do not understand the concept of time before they understand the concept of speed; in fact, the reverse is the case, with speed being mastered well in advance of time. It has also become evident that neither time, speed, nor distance is an intuitive notion but rather that all three concepts undergo lengthy and regular developmental sequences. Not very much can yet be said, however, about the third part of Einstein's question, the part dealing with how acquisition of each concept influences acquisition of the others. Nor can we say very much about the types of experiences that contribute to understanding of each concept or about why full understanding of each of them is not achieved earlier. In short, Einstein's question remains a timely challenge: we hope it will be answered with speed in the not too distant future.

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