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ABSTRACT

The purpose of this study was to determine how children at different ages understand the concept of temperature, examining particularly the logicomathematical aspects of the concept. In doing so, three developmental approaches were compared: (1) Piaget's structuralist approach; (2) Siegler's rule assessment approach; and (3) Anderson and Wilkening's functional measurement approach. In order to assess children's understanding of temperature via the three developmental approaches, tasks with two variables were selected, namely, heating varying amounts of water by varying numbers of candles. Subjects were 96 middle-class Israeli children aged 4 to 11. Findings, among others, indicate that there are both commonalities and differences in children's development of the concept of temperature across various methodologies. In the Piaget and Siegler approach, children's development proceeded from centering on one variable to attending to two variables without coordinating them to attending to two variables and coordinating them. In the Anderson and Wilkening's approach, development proceeds from integrating two variables via integration rules of first addition, then subtraction, and finally division. Children who concentrate on one variable via Piaget's and Siegler's tasks integrate these variables via Anderson and Wilkening's tasks. This suggests that the latter two approaches may underestimate children's intellectual capacities. (JN)

The Development Of The Concept Of Temperature When Assessed Via Three Developmental Models

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The present study is based on part of a PhD thesis conducted by Pnina Frenkel and guided by Sidney Strauss. Due to space considerations, most of the thesis and analyses cannot be reported here. Some data analysis and the writing of the thesis is currently being concluded. This is Working Paper Number 46 of the Tel-Aviv University Unit on Human Development and Education. Part of this report was presented at the Biennial Meeting of the Society For Research In Child Development held in Toronto, April 26-29, 1985.

The Development Of The Concept Of Temperature When Assessed Via Three Developmental Models

The main purpose of the present study was to determine how children at different ages understand the concept of temperature where, in particular, we looked at the logicomathematical aspects of this concept. In so doing, we compared three developmental approaches: (1) Piaget's structuralist approach, (2) Siegler's rule assessment approach, and (3) Anderson and Wilkening's functional measurement approach.

In Piaget's structuralist approach, children construct forms of knowledge about the physical, mathematical, logical, social, biological, etc. world (Piaget, 1970; Piaget & Inhelder, 1974). He argues that these forms of knowledge are conceptual products that are constrained by the structure of logic children have constructed. The methodology Piaget uses is the clinical technique which is an open-ended interview where children produce judgments about the problems posed and also are asked to explain or justify their judgments.

Siegler's rule assessment approach is a qualitative information processing approach (Siegler, 1976, 1981, 1983; Richards & Siegler, 1982). The picture drawn by Siegler is that of a child who is rule-governed. These rules can be described in the form of binary decision trees, although they can be described otherwise (Siegler, 1983). Development often proceeds from rules that allow children to attend to one, dominant variable; to rules that allow them to attend to the second variable if the first is held constant; to rules where children attend to both variables but where they do not have a way to coordinate them; to rules that allow a coordination of the variables. The methodology used by Siegler can involve a forced choice procedure where children are not asked to justify their judgments.

Anderson and Wilkening's functional measurement is an information processing approach (Anderson, 1980, 1981, 1982; Cuneo, 1978; Levin, Wilkening, & Dembo, 1984; Wilkening, 1981, 1982; Wilkening & Anderson, 1982). One of the major components of this approach is that children integrate information (variables) at a very early age and that development is characterized by changes in the algebraic rules they use to integrate that information. These algebraic rules can proceed from simple ones (addition/subtraction) to more complex ones (multiplication/division). The methodology accompanying this approach often involves presenting one stimulus and asking a child to make a subjective estimate on a continuous scale of its, say, temperature, as in the case of the present study.

In order to assess children's changing understanding of the concept of temperature via the three developmental approaches, we chose tasks with two variables, where varying amounts of water was heated by varying numbers of candles. Some work in this area was conducted by Strauss, Stavy, & Orpaz (1977) and Strauss & Stavy (1982). They analyzed the tasks into their component parts and claimed that these tasks measure how children think about ratios, where the numerator is the number of candles and the denominator is the amount of water. In their studies, children were presented two containers of water which were heated by a certain number of candles. They were asked if they are the same temperature and, as a consequence, they

were being asked to compare the ratios of number of candles/amounts of water.

Strauss & Stavy (1982) argued further that it is possible to manipulate these variables in three characteristic ways. The first is to vary the numerator only where two containers of equal amounts of water are presented and are heated by different numbers of candles, say, 1 candle and 2 candles. This task is called the <u>direct function</u> task since a change in the numerator (number of candles) changes the ratio (temperature) directly. In the present example, the cup with more candles is hotter. The second way to manipulate these variables is to vary only the amounts of water. Here two cups of unequal amounts of water are heated by the same number of candles, say, 1 candle. This task is called the <u>inverse function</u> task since a change in the denominator (amount of water) changes the ratio (temperature) inversely. In the present example, the cup containing less water is hotter. The third way to manipulate these variables is to vary both of them. When they are varied proportionally, the temperature remains the same. This task is called the <u>proportions</u> task. An example would be that one cup is 1/3 filled and has 1 candle heating it and the second cup is full and has 3 candles heating it.

In the present study we gave tasks from each of the three developmental approaches to children from a wide age range. Each child was given tasks from each of the three approaches. Given the comparative nature of the study, we will now present the methods section where at the end of the description of the procedure for each approach, we present the hypotheses for that approach.

METHOD

We divide this section into three parts: those for Piaget, Siegler, and Anderson and Wilkening.

Piaget's Structuralist Approach .

Three tasks were presented to each child: the (1) direct function, (2) inverse function, and (3) proportions tasks. In all three cases the materials were presented to the children and all the relevant manipulations were carried out in front of them. The tasks given to the children are presented in Figure 1. We illustrate the procedure with the direct function task. The experimenter presents two same-size cups and fills them to the same height. She then says, "The water in these cups are the same temperature. Now let's put them over the candles for the same amount of time. Let's pretend the candles are lit. (The experimenter puts them over the unlit candles at the same time, holds them over the candles for several seconds, and removes them from the candles at the same time). Is the water in the two cups the same temperature or is one of them hotter"? (The order of the two possibilities - same temperature/hotter - was alternated across tasks). If the judgment was that one is hotter, they were asked to indicate which was hotter. The children were then asked to justify their judgment: "Why do you think this one is hotter/they are the same temperature"?

Insert Figure 1 around here

There are four hypotheses for Piaget's approach. The first three

hypotheses deal with children's judgments on individual tasks. The first, which deals with age effects, is that more older than younger children will solve the tasks correctly. The second hypothesis, which deals with the tasks' differing difficulties, is that there will be significant task differences with the direct function being the easiest and the inverse function and proportions being of equal difficulty and more difficult than the direct function task. The third hypothesis is that there is a significant age X task interaction.

The fourth hypothesis pertains to patterns of judgments. We predicted that there are three patterns of judgments: a correct judgment on the direct function task and incorrect judgments on the inverse function and proportions tasks (+--); correct judgments on the direct and inverse function tasks and an incorrect judgment on the proportions task (++-); and correct judgments on all three tasks (+++). The fourth hypothesis had two parts: (a) the judgments scale to form the patterns, and (b) there is an age effects for the patterns.

Siegler's Rule Assessment Approach .

In Siegler's methodology, the investigator first hypothesizes rules that are thought to be the likely ones children have about the content of interest. In our case, the rules are about heating varying amounts of water with different numbers of candles. A guide for determining rules has been provided by Siegler (198?). The rules for solving tasks in our study are found in Figure 2.

Insert Figure 2 around here

The investigator decides which of the variables is the most psychologically salient and, based on that decision, posits that that variable will be attended to first. In our case, the number of candles is more psychologically salient than the amount of water. Rule 1 asks if the number of candles is equal. The second variable, water in our case, is then attended to, but only under the condition that the first variable is held constant. Rule 2, paraphrased, asks if the amounts of water are the same under the conditions that the number of candles is the same. Rule 3 allows children to attend to both variables but there is no coordination between them. In our case, if the number of candles and the amount of water is greater in the same cup, Rule 3 predicts a guess on the part of the child. In Rule 4, children attend to both variables and can coordinate them.

Insert Figure 3 around here

The next step in Siegler's rule assessment method is to construct a set of tasks that will test the existence of the proposed rules. The tasks we devised for such a test are found in Figure 3. In Siegler's methodology we then superimpose the hypothesized rules on the tasks and predict how children who consistently use the r es will perform on the various tasks.

We illustrate how to read Figure 3 with the example from task category 4: conflict candles. Here we see in the first task that in one cup (on the right), 3 units of water are heated by 2 candles, and in the cup on the left, 2 units of water are heated by 1 candle. In this task, the correct judgment is that the cup on the right is hotter (signified by an asterik next to that cup). A child who uses Rule 1

attends to the number of candles only and judges that the cup on the right is hotter because it has 2 candles heating it as compared to 1 candle heating the other cup. This judgment is correct as indicated by the 100% that appears in the intersect between Rule 1 and this task type. A child who uses Rule 2 produces the same judgment because the number of candles is not equal and that rule leads to the judgment that if the number of candles are unequal, the cup with more candles is hotter. Once again, the judgment is correct. Children using Rule 3 attend to both variables but cannot coordinate them. In this task both the number of candles and amounts of water are greater in one cup, so the children guess. This is indicated by 33% since the children can guess one of three judgments: they are the same temperature, the left cup is hotter, and the right cup is hotter. Finally, children using Rule 4 have the ability to coordinate the variables and they judge correcly on this task. When reading the developmental trend predicted by the superimposition of the rules on this task, we see that there is a predicted U-shaped behavioral growth curve.

Notice that there are parallels between some of Siegler's tasks and those of Piaget: (1) task type 2 (candles) is equivalent to Piaget's direct function task; (2) task type 3 (water) is equivalent to Piaget's inverse function task; and (3) task type 6 (conflict balance) is equivalent to Piaget's proportions task. These parallels allow a comparison of Siegler and Piaget.

In Siegler's methodology, the children are presented the materials and the cups are placed over candles as in the Piagetian tasks. They are asked, "Is the water in the two cups the same temperature or is one hotter"? If they judge that the water in one cup

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is hotter, they are asked to indicate which one is hotter. No justifications are asked of the children.

Each child is given a total of 12 tasks. There are six task types and two tasks were given per task type. The criteria for a child using a rule were that s/he had to produce judgments consistent with that rule on at least 10 of the 12 tasks. There were further restrictions for each rule. For Rule 1, a child had to produce an incorrect judgment on both tasks from task type 3 (Water), whereas for Rule 2, a child had to produce a correct judgment on both task type 3 tasks. This is because judgments on that task are what differentiate Rule 1 from Rule 2. For Rule 3, all 6 of the first three task types had to be solved correctly and no more than 4 of the 6 conflict tasks (the last three task types) had to be judged correctly in order that a child be considered to be a consistent Rule 3 user. Finally, for Rule 4, a child had to produce correct judgments for all of the 6 conflict tasks.

There were two hypotheses for Siegler's approach. The first was that we will find the predicted developmental trends for each task. The second was that we will find the rules predicted by Siegler's methodology and that they will be age-related.

Anderson and Wilkening's Functional Measurement Approach.

In order to test the functional measurement approach we presented 18 tasks. There were a total of 9 tasks in a 3 X 3 matrix and each task was presented twice. The tasks appear in Figure 4. Notice that there is a parallel between some of these tasks and those of Piaget and Siegler. When reading Figure 4 from left to right for each row we see that the amounts of water remain constant and the number of

candles increases. The comparison of children's estimates for these tasks is equivalent to Piaget's direct function task and the candles tasks for Siegler. When reading Figure 4 from top to bottom for each column we see that the number of candles is constant and the amounts of water increase. The comparison of children's estimates for these tasks is equivalent to Piaget's inverse function task and Siegler's water tasks. Finally, when reading Figure 4 on the diagonal we see that the number of candles and amounts of water change proportionally. This is equivalent to Piaget's proportions task and Siegler's conflict balance tasks. These parallels allow a comparison of children's solutions on equivalent tasks from different methodologies.

Insert Figures 4 and 5 around here

The children were asked to estimate the temperature on an instrument illustrated in Figure 5. The instrument was placed in front of a child who was shown how it works. A red strip could be pulled out and the child was told that when the water is very hot it gets pulled out very far and when it is not very hot it does not get pulled out very far. The experimenter demonstrated its use to the children and they were then asked to show, via the instrument, hot water, very hot water, and tepid water. If the children made the proper manipulations, the experiment began.

Notice that there were two anchors that set the outer limits for the children's estimates. One was a cup 1/4 filled with four candles under it and it represented a temperature that was hotter than the hottest temperature that was to be given to the children. Similarly, a cup of cold water not heated by any candle served as an anchor for water that is colder than the coldest water presented in the study. And finally, the instrument was devised such that a ruler was placed on the experimenter's side so that when the red strip was pulled out to varying lengths, the experimenter could record the child's estimate of the temperature.

The procedure for the experimental conditions was that the experimenter presented a cup of water filled to a determined height and placed it over a certain number of candles and asked the child, "Show me how hot the water is with the red strip." After the child pulled out the strip to make the estimate, the experimenter placed the red strip back to the original starting place and presented the next task. This was continued until all 18 tasks were presented.

There was one hypothesis from Anderson and Wilkening's approach: there is a developmental trend such that younger children use simple algebraic integration rules such as addition and subtraction and older children use complex integration rules such as division.

SUBJECTS

The subjects were middle-class children from Ramat Hasharon and Ramat Gan, two cities near Tel-Aviv. A total of 96 children were tested. There were 6 age groups and 16 children per age group, with 8 boys and 8 girls in each age group. The ages of the children per age group were 4,5,6,7,9, and 11. The children were interviewed individually in the kindergarden or school where they learned. The order of presentation of the tasks across approaches was counterbalanced and the order of presentation of tasks within each approach was randomized. There were generally three testing periods,

one for each of the approaches. The testing periods were given within a one week span. Each testing period lasted for approximately 10 - 20 minutes.

RESULTS

The data will be presented in the following order: (1) Piaget's structuralist approach, (2) Siegler's rule assessment approach, and (3) Wilkening and Anderson's functional measurement approach.

Piaget's Structuralist Approach

There were four hypotheses about children's understanding of the direct function, inverse function, and proportions tasks. The first hypothesis was that there are significant age effects for judgments on the tasks: more older than younger children will produce correct judgments, and the second was that there are significant differences among the tasks.

Insert Figure 6 here

Data relevant for the hypotheses are found in Figure 6. A two-way 6 (age groups) X 3 (tasks) analysis of variance for repeated measures was run and main effects were found for age $F(5, 90) = 28.77$, $p<.0001$ and for tasks $F(2, 180) = 91.61$, $p<.0001$. Hence, the first two hypotheses were confirmed.

The third hypothesis, that there is a significant age by task interaction, was confirmed. $F(10, 180) = 6.77$, $p<.0001$. The interaction was the result of differing slopes for the three tasks across ages. The direct function task was judged correctly by practically all of the children (there was a ceiling effect), while the increase in correct judgments for both the inverse function and proportions tasks was gradual.

The fourth hypothesis had two parts: (a) Children's judgments on the tasks produce three patterns that scale: a correct judgment on the direct function task only (+--) ; correct judgments on both the direct function and inverse function tasks (++-); and correct judgments on all three tasks (+++), and (b) there is an age affect for patterns: more younger children display the (+--) pattern, more older children display the (+++) pattern, and children of intermediate ages produce the (++-) pattern. Both hypotheses were confirmed.

Insert Table 1 here

The relevant data are found in Table 1. As can be seen, 87 out of our 96 children produced one of the three patterns. A Guttman scalogram analysis indicated that the patterns scale. The coefficient of scalability was .89 and the coefficient of reproducibility was .97. This confirms the first part of our fourth hypothesis.

As for the second part of the fourth hypothesis, relating age and patterns, we can see in Table 1 that 51% of the children produced the (+--) pattern, only 13% produced the (++-) pattern, and 36% of the children produced the (+++) pattern. Of those who produced the first pattern (+--) most are from the two youngest age groups: 61% of the children who display that pattern are 4 and 5-year-olds. The number of children producing this pattern decreases with age. Similarly, of those who produce the third pattern (+++), most, 78%, are from the two

oldest age groups, ages 9 and 11. Few of the youngest children produce this pattern and it is only by age 9 that a majority of the children produce it. Because there were so few children who produced the (++-) pattern and because they were fairly evenly distributed across the various ages, we cannot make any strong claims about age effects for that pattern. The data just presented indicate that there is an age effect for producing the patterns; however, this conclusion must be offered with some hesitation since the intermediate pattern was produced by so few children.

A further point pertains to children's justifications about their judgments: children's justifications are age-related, where younger children produce unidimensional and older children produce bidimensional justifications. There were two predominant justifications, those referring to: (a) one dimension only either the number of candles or the amount of water (e.g., "Here there are more candles than here so it's hotter.") and (b) both dimensions (e.g., "Here there is more water and more candles, so the water is hotter.")

For space reasons, we cannot enter into a detailed account of the data here. It appears that younger children are more likely than older children to justify their judgments with unidimensional reasoning and older children are more likely to justify their judgments with bidimensional justifications. The cutoff point seems to be somewhere around age 9, where below this age the predominant justification is unidimensional and above this age, the predominant justification is bidimensional.

Siegler's Rule Assessment Approach

Before presenting data about the hypotheses, we note that there were no significant differences between children's judgments on the two tasks presented for each task type so these data were combined.

Here there were two hypotheses. The first was that we would find the predicted developmental trends for each task type. We ran a one-way ANOVA for each analysis. The data are found in Table 2.

Insert Table 2 around here

For the first task type, balance, we predicted no significant differences between age groups because children at all age groups should have solved the tasks correctly. The findings were that there were significant differences between age groups F (5,90) = 4.31, p<.001. As can be seen in Table 2, the significant differences were a result 14 out of 16 children in age group 1 who solved the tasks correctly, where all 16 of the children in each of the other age groups solved them correctly. The significant differences, then, were due to the small amount of variance being located in one age group. Although the differences were significant, we claim that the hypothesis was confirmed.

For the second task type, candles, we also hypothesized no significant differences between age groups. Once again we found that the hypothesis was not confirmed F (5,90) = 2.83, p<.002. The findings in Table . indicate that 9 out of 96 children solved this task type incorrectly and they were located in the first three age groups.

The hypotheses from the remaining four task types were confirmed in part. For task type 3, water, we hypothesized a dramatic

improvement with age and the data confirmed our hypothesis F (5,90) = 19.15, p<.0001. For task type 4, conflict candles, we hypothesized a U-shaped behavioral growth curve. We found a drop in performance over ages group but the expected increase in correct judgments was not found F(5,90) = 3.27, p<.01. For the fifth and sixth task types, conflict water and conflict balance, we hypothesized a gradual improvement with age. In both cases, the data confirmed the hypothesis: F (5,90) = 7.14, p<.0001 and F (5,90) = 16.14, p<.0001, respectively. In sum, most of the analyses confirmed Siegler's first hypothesis.

The second hypothesis in Siegler's approach was that the predicted rules will be found and that they will be age related. The data relevant to this hypothesis are found in Table 3. Rule 1 was exhibited by 46 children (48% of the entire sample) and it was found predominantly among the four youngest age groups (ages 4,5,6, and 7). We found that this rule could be broken down further into two other rules, which we describe below. Rule 2 was exhibited by relatively few children 9, or 9% of the sample, and there did not appear to be an age trend of its appearance. Rule 3 was exhibited by 12 children (13%) and it appeared predominantly among children from the three oldest age groups: ages 7,9, and 11. Rule 4 was exhibited by 23 children (24%) and it was found mostly among the children from the two oldest age groups: ages 9 and 11.

Insert Table 3 around here

We mentioned above that Rule 1 can be broken down further into two rules and we now show how that is the case (see Table 3). In the first rule, Rule 1A, children attend to the amount of water. They argue, in the case of task type 3 - water - that the cup with more water is hotter. These children constituted 24 of the 46 (52%) of the children who use Rule 1 and they were most prominent among the 4-year-olds with a steady decline of Rule 1A use over age groups. In the second rule, Rule 1B, children attend to the number of candles. They argue, in the case of task type 3, that the cup with more candles is hotter. A total of 22 (48%) of the Rule 1 children exhibited Rule 1B and they were found among the four youngest age groups: ages 4,5,6, and 7. In both the Rule 1A and 1B cases, the children attended to one variable and their reasoning was unidimensional.

In sum, we found the hypothesized rules and found that they were age-related. In addition, we found an additional rule that we had not hypothesized. In general, development seems to proceed from Rule 1: attending to one variable (either the number of candles or the amount of water) to Rule 4: attending to both variables and coordinating them. Rules 2 and 3, that state that one attends to one variable under the condition that the second is held constant, and one attends to two variables without coordinationg them, respectively, were hardly found.

Anderson and Wilkening's Functional Measurement Approach

The hypothesis from this approach was that younger children use simple algebraic rules such as addition and subtraction and older children use more complex integration rules such as division. The relevant data are found in Figures 7 and 8.

Insert Figures 7 and 8 around here

Figure 7 presents some of the relevant data. On the vertical axis we have the children's subjective estimate of temperature and on the horizontal axis we have the number of candles. Notice that the use of the addition rule is found when there are parallel curves and the top curve is the cup with 3 units of water, the bottom curve is the cup with 1 unit of water. and the intermediate curve is the cup with 2 units. Subtraction is indicated by parallel curves with the curves from top to bottom being 1,2,and 3 units of water.

In Figure 7 we see that the children from the two youngest age groups (ages 4 and 5) use the addition integration rule; the children from age group 6 do not have a discernible integration rule; the children from age group 7 use the subtraction integration rule; those from age group 9 use both the subtraction and division rules; and the 11-year-olds use the division integration rule. These data support the hypothesis.

In Figure 8 we are dealing with the same data as in Figure 7 except that the amounts of water are now on the horizontal axis. What we see here is that the distances between the curves is greater in Figure 8 than in Figure 7 and their slopes are not as deep. This suggests that the children weighted the number of candles more than the amounts of water. In addition, we see from Figure 8 that the children in age groups 4 and 5 used the direct function for both the number of candles and amounts of water. We know this because the curves rise from left to right for these two age groups. For age group 6 children we see horizontal and parallel curves. This can be a consequence of two main types of data. First, it could be the case that the children did not attend to the varving amounts of water. Second, it could be that some of the children used direct function reasoning and others used inverse function reasoning resulting in each one essentially cancelling out the other. Finally, the children from age groups 7,9, and 11 used inverse function reasoning for the amounts of water. We know this because the curves fall from left to right.

In sum, the data from Anderson and Wilkening's approach fit the hypothesis generated from that approach.

Discussion

The data from the present study allow some tentative conclusions. Due to space limitations we cannot discuss them all, nor can we expand on those we mention here

First, we have confirmed many predictions from the developmental approaches where the content was the concept of temperature. This means we can add this new content to the list of concepts that have yielded to the developmental models tested here

Second, because each child was administered tasks from each of the three developmental models and because the children behaved in ways consistent with the predictions from the models, it appears that the different methodologies constrain, and possibly even produce, these very behaviors. For an expanded version of this point, see Strauss & Ephron-Wertheim, (in press) and Strauss & Levin (1981).

There appear to be both commonalities and differences in children's development of the concept of temperature across various methodologies. For both Piaget and Siegler, children's development proceeded from centering on one variable to attending to two variables

without coordinating them (this was found in relatively few children) to attending to two variables and coordinating them. For Anderson and Wilkening's approach, development proceeds from integrating two variables via integration rules of first addition, then subtraction, and finally division. Notice here that the very children who centrate on one variable via Piaget's and Siegler's tasks integrate these variables via Anderson and Wilkening's tasks. This suggests that the latter two approaches may underestimate children's intellectual capacities.

The ability to solve the direct function, inverse function, and proportions tasks for the three approaches was remarkably similar. For all three approaches we found that virtually all of the children from the earliest age onward were able to solve the direct function task. The transition from the ability to judge incorrectly to judging correctly on the inverse function task was found to occur between ages 7 and 9 for both Piaget's task and Siegler's tasks, while it occured between ages 6 and 7 for Anderson and Wilkening's tasks. The proportions task was solved by 75% of the 9-year-olds and 100% of the 11-year-olds for Piaget's task; by 63% and by 83% of the 11-year-olds for Siegler's tasks; and by similar percentages for Anderson and Wilkening's tasks.

As for the ages when children change from one mental state to the next, we found that for both Piaget and Siegler, the change from centration to attending to two variables without coordination occurs at approximately age 7 and the change to coordination occurs at around age 9. For Anderson and Wilkening, the transition from simple algebraic rules (addition/subtraction) to more complex ones (division) occurs at age 9.

The overall picture presented here is that each of the approaches allows a unique way to understand the development of children's concepts of temperature, yet they have some overlap in their interpretations of the data. The details of these similarities and differences are currently being worked out for the work described in this report and for a second set of experiments conducted for the same purposes where same and different temperature water was mixed.

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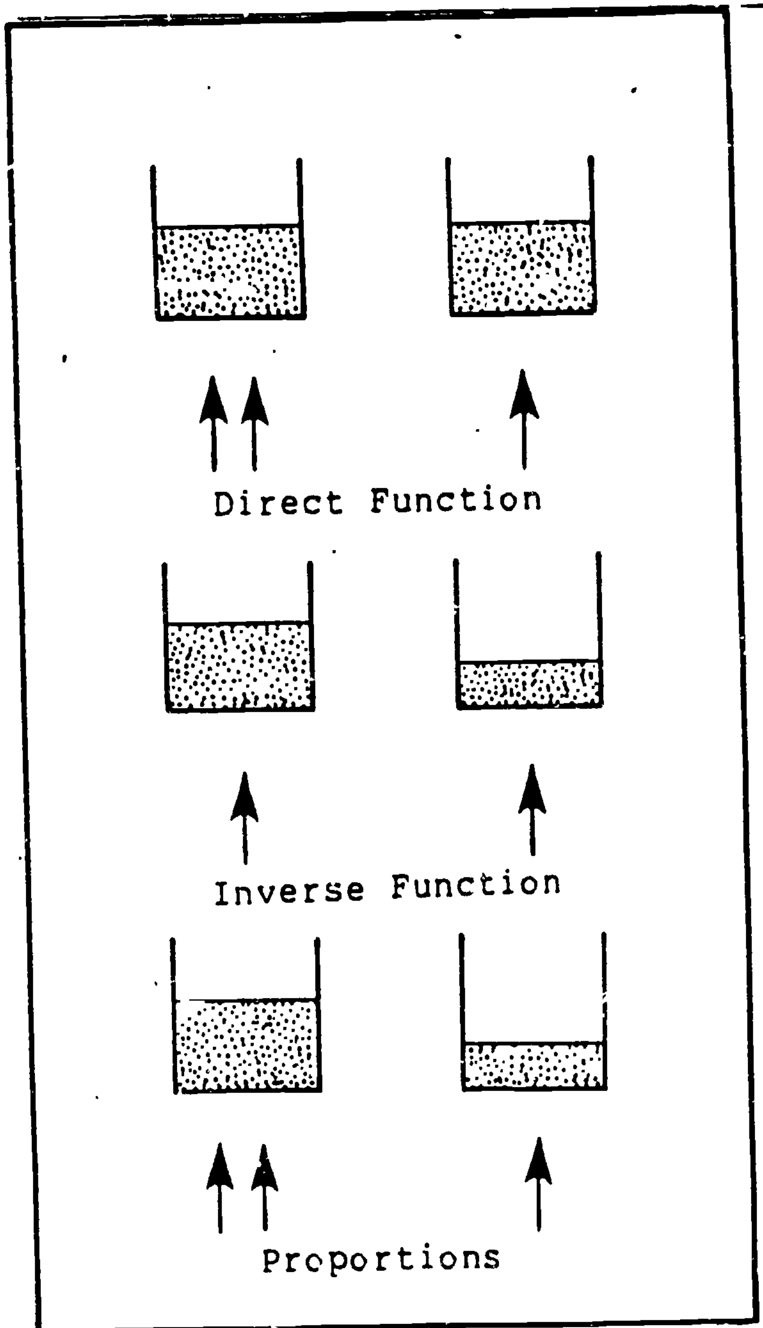


TASKS FOR DIRECT FUNCTION, INVERSE FUNCTION, AND PROPORTIONS: PIAGET'S STRUCTURALIST APPROACH

FIGURE 1

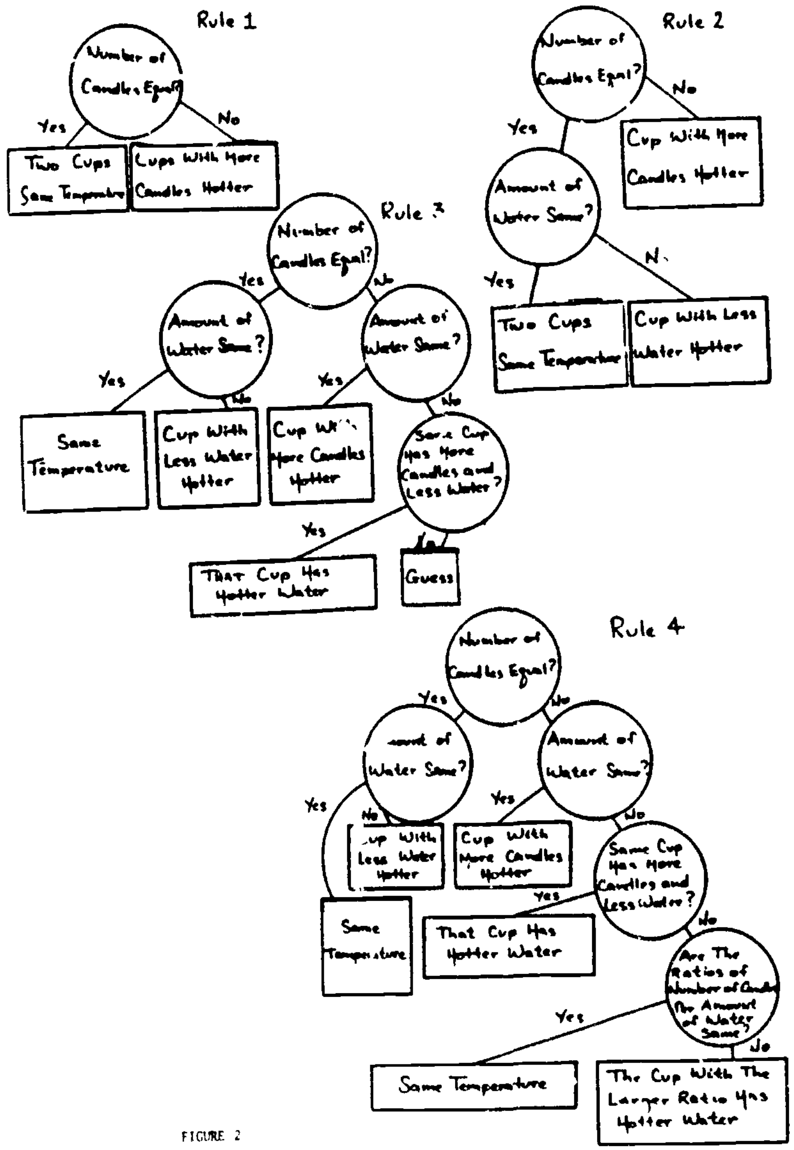


FIGURE 2

DECISION TREE MODEL OF RULES FOR SOLUTIONS ON THE TEMPERATURE TASKS

FIGURE 3

Predicted Developmental Trends on Siegler's Tasks

Predicted Developmental Trend	Rules 4	3	2	1	Tasks		
No change- all children at high level	103	100	100	100		Balance	1
No change- all children at high level	100	100	100	100		Candles	2
Dramatic improvement with age	100	100	100	0		Water	3
U-shaped behavioral change or drop without upturn	100	33	100	100		Conflict Candles	4
Gradual improvement with age	100	33	0	0		Conflict Water	5
Gradual improvement with age	100	33	0	0		Conflict Balance	

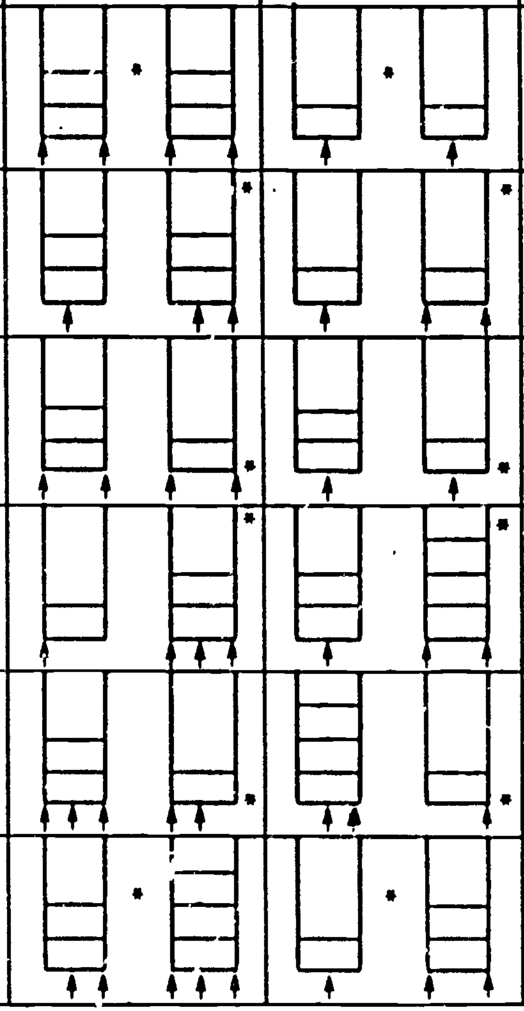


FIGURE 4

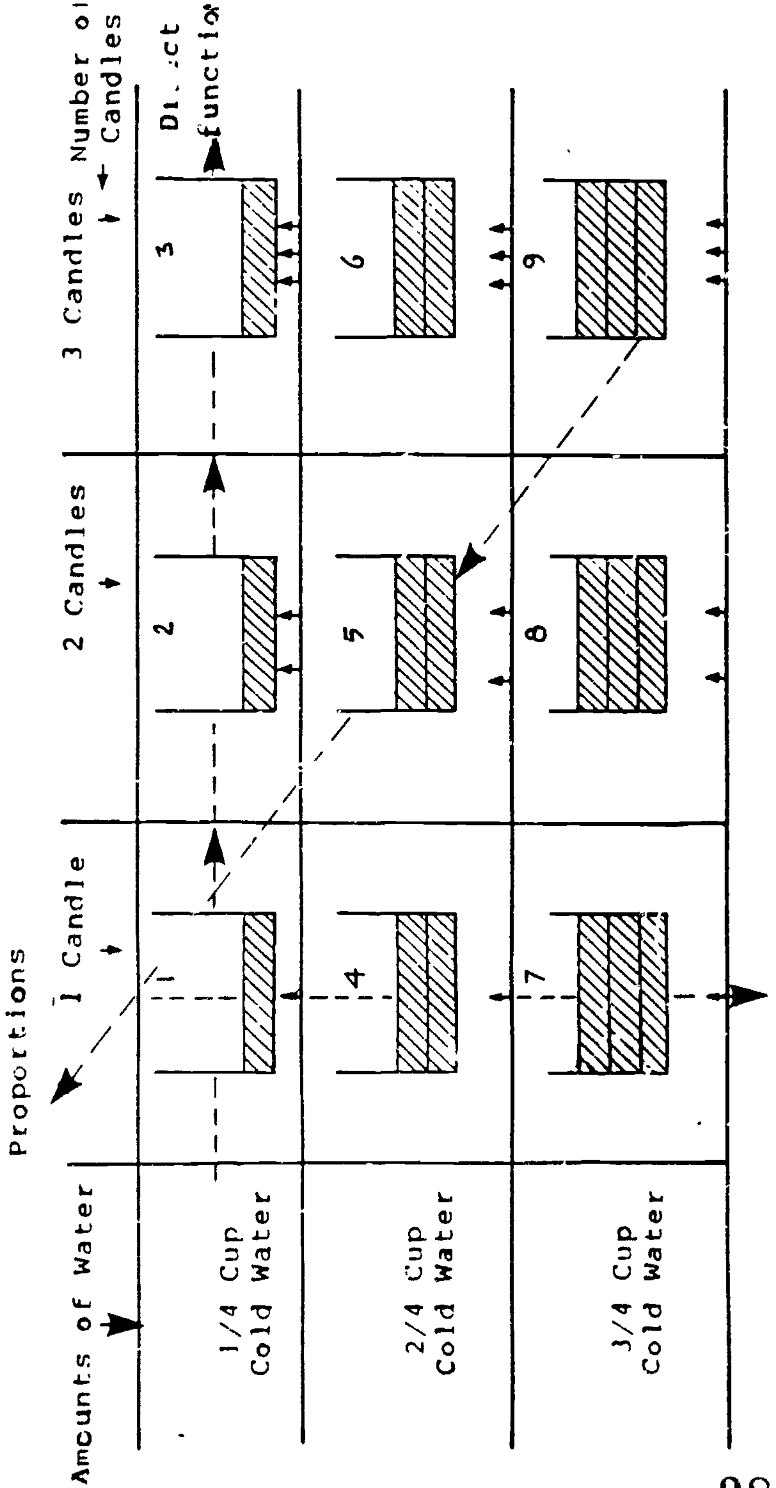
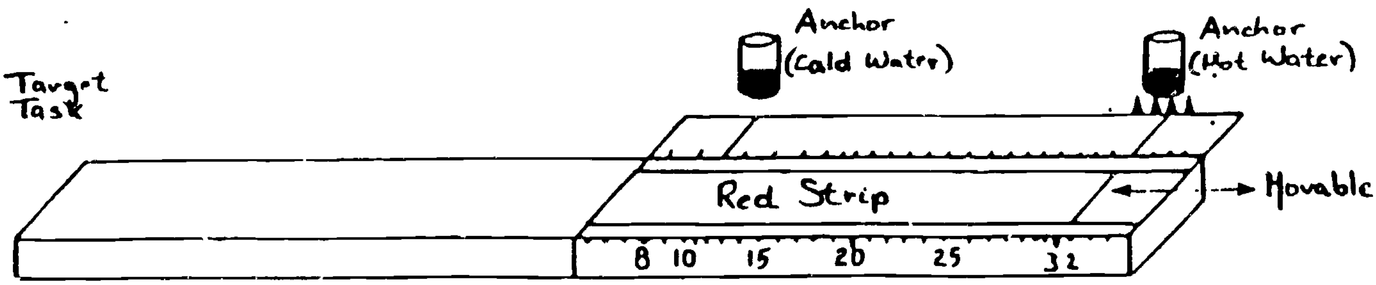


FIGURE 5



MEASUREMENT SCALE FOR TEMPERATURE ESTIMATES

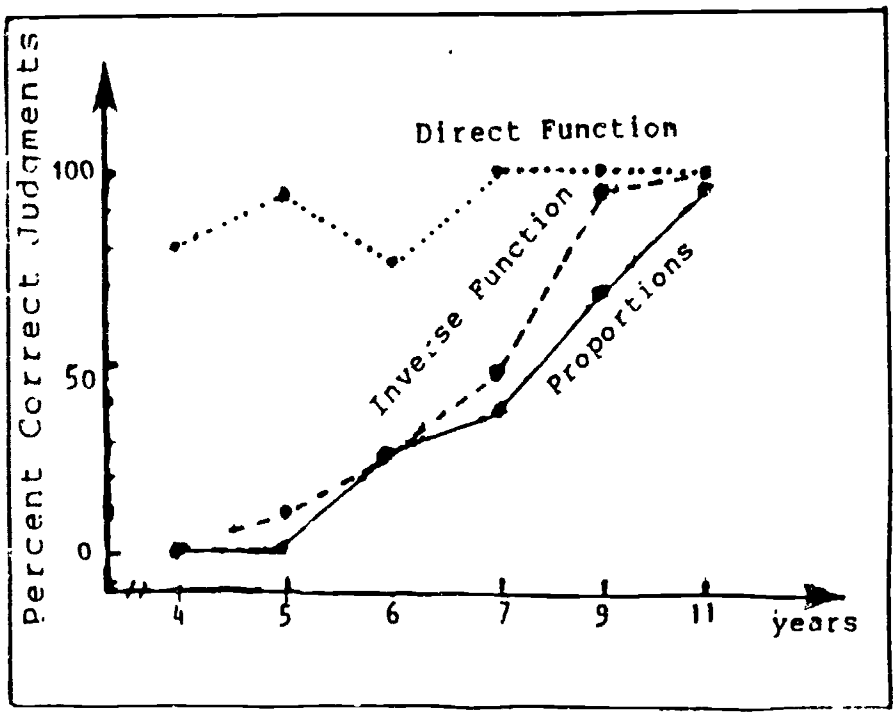


FIGURE 6

Percent Correct Judgments On The Direct Function, Inverse Function and Proportions Tasks

TABLE 1

Frequency of Children Conforming to Predicted Developmental Sequence According to Piaget's Model

	Ages 4	5	6	7	9	11	Tota
Direct function	14	13	8	8	1	0	44
Direct function + Inverse function	0	1	2	2	4	2	11
Direct function + Inverse function + Proportions	0	1	1	5	11	14	32
							87

TABLE 2

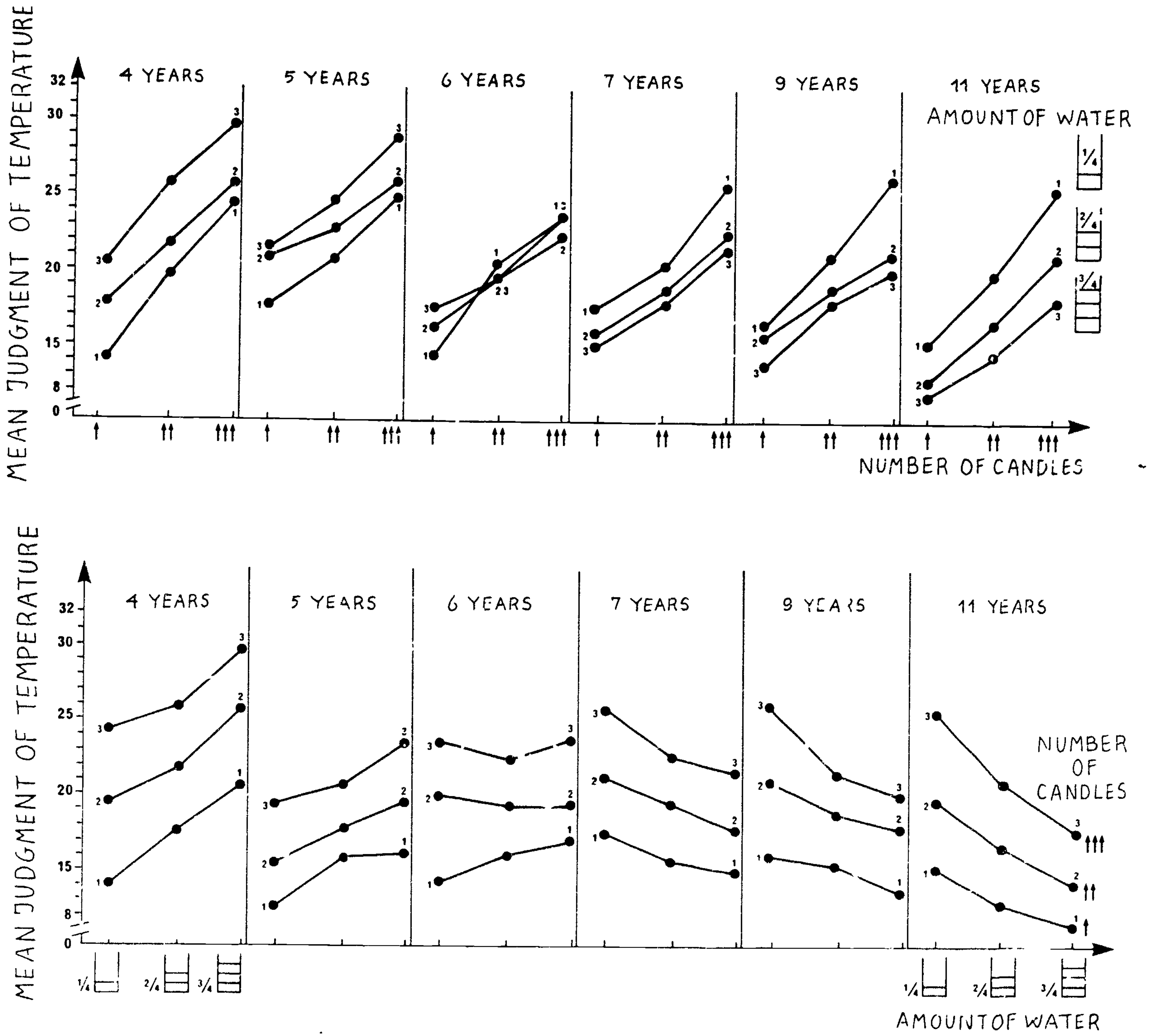
Frequency of Children Producing Correct Judgments on Siegler Tasks

Type of Task	Age 4	5	6	7	9	11	Predicted Development Trend
Balance	14	16	16	16	16	16	No change - all children at high level
Candles	13	14	12	16	16	16	No change - all children at high level
Water	1	4	3	8	14	15	Dramatic improvement with age
Conflict Candles	14	15	13	10	7	5	U-shaped behavioral change or drop without upturn
Conflict Water	0	0	2	6	11	11	Gradual improvement with age
Conflict Balance	1	1	3	7	10	14	Gradual improvement with age

TABLE 3

Frequency of Children Using Rules According to Siegler's Model

Rules	Age 4	5	6	7	9	11	Total
1	12	12	11	8	2	1	46
2	1	4	0	1	3	0	9
3	0	0	1	4	4	3	12
4	0	0	0	3	7	12	23
1A	8	7	4	3	2	0	24
1B	4	5	7	5	0	1	22



MEAN JUDGMENT OF TEMPERATURE AS A FUNCTION OF NUMBER OF CANDLES AND AMOUNT OF WATER