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ABSTRACT

In this report on cognitive processes, a discussion of the rationale and assumptions used by investigators explains the experimental procedures. To determine actual cognitive problem-solving processes, (rather than inferring them from results), subjects in these studies were presented with a problem and allowed to ask a sequence of questions which the experimenter answered and recorded. The sequence of questions is called the subject's tactic and is identified by the number of questions, type of questions, and the temporal order of the questions. It is recognized that problems are built with a certain logical structure (intrinsic difficulty) and a certain language structure (extrinsic difficulty). An ideal tactic approximates the logical structure of the problem, has no order reversals, and is not redundant. Good tactics are those which provide enough information to solve the problem. A system of numerical indices was developed for scoring tactics. Previous research using these instruments to investigate individual cognitive processes and the effects of language on these processes has revealed that concrete and verbal languages run through a larger variety of logical structures than do abstract symbolic languages. (MH)

PSYCHOMETRIC LABORATORY

ON COGNIZING COGNITIVE PROCESSES

by

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I hope that the reasons for the purposeful redundancy in the title will become apparent in what follows. In the first place within the vast area of cognitive studies we will be only concerned with cognitive processes as such in a problem solving situation. Though we have explored the relationship of cognitive processes to personality and perceptual variables as well as to autonomic processes (1), these aspects will not be discussed here. Cognitive processes in problem solving situations will be here defined as the sequence of psychological (mental) operations that occur when a human subject solves a problem. In other words we will try to discuss some of the characteristics of the set of events and of the ordered relational system that connects these events when subjects have to find out the solution of a problem.

Our specific approach since 1954 has been experimental including and not excluding, as a first step the observation of people when solving problems. That is: "Plus on regarde et plus on voit. Mais plus aussi on voit ou il faut regarder" (10).

In the vast literature that has accumulated during the last 15 years, it is at times difficult to understand unambiguously the meaning of concepts used, and the language used to express them. Thus in the present paper we shall try to define as rigorously as we can the concepts and the operations performed to reduce as much as possible the risk of being uncertain. A similar effort will be made with regard to the assumptions made. We thus hope to make our procedures reproducible, and our conclusions testable, so that the interpretations of the results, whatever they might be, will not be biased by accidental circumstances. Among these we include interaction subject-experimenter that at times creeps in in unexpected ways in the actual experimental situation.

To fulfill our aims we explore the sequence of questions that a subject asks in order to solve a problem when the experimenter provides the answer corresponding to each question that the subject asks. This sequence of questions is called a tactic, and tactics are identifiable in terms of number of questions asked, type of questions, and order in which they occur. Tactics begin with the first question asked and end when the subject solves the problem (whether the solution is right or wrong) or when he does not want to ask further questions. Instead of "inferring" the process that mediates between the presentation of the stimulus and the response, by concentrating on the study of these responses we analyze the chain of events that the subject goes through when solving a problem. In some senses this approach is a reversal of some of the current methods and to a certain extent it eliminates some gross experimenter's biases in inferring processes.

In the first part of this presentation, we will refer to the assumptions that are at the basis of our conceptualization of the problem, methodological problems will be discussed next, and thirdly some results will be presented.

Assumptions

In the first place we assume that there are rules of correspondence between specific processes and specific tactics. To spell out the transformation that holds between the domain of processes and the codomain of tactics is a major psychological task. Assuming a one-one correspondence, means that each tactic is the image of one and only one process. What subjects do (tactics) would be the exact counterpart of their process. Nevertheless the whole history of psychology (including the work of the introspectionists, the anecdotal descriptions of observable behavior, the interpretation of tests and of clinical material, etc.) seems to indicate that this is not often the case. And this is unfortunate since our task as psychologists would be considerably simplified and our discipline would be more precise, though aesthetically perhaps less appealing, if one-one transformations would hold.

It is more likely that the correspondence between processes and tactics is of the many-one type, that is each process corresponds to one and only one tactic though several processes may correspond to the same tactic. In this case a rule of correspondence or function can be described by specifying which processes converge in the same tactics. As a matter of fact this is what we usually do in our interpretation of psychological material, when assuming that the same observable behavior, for instance a verbalized opinion, may result from different types of attitudes. The idea of vicarious psychological activities is related to this idea.

If the correspondence between processes and tactics were of the one-many type, then confusion would prevail unless the hierarchical order of the system process → tactic is reversed. In this case tactics become the domain and processes the codomain. This of course would imply that processes are function of tactics, which apparently throws us right into the controversy typified by central versus peripheral theories.

I personally would prefer to assume that observable behavior (tactics) is a function of the subject's processes and not vice versa. Therefore, the main experimental task consists in the design of appropriate instruments and experiments to find out the one-one or many-one type of correspondence that holds.

In the second place the technique that we use assumes that, within limits, subjects are free to ask questions. The definition of the limits of each subject's interval of freedom is an overwhelming task, but in many ways this is not an either/or type of dilemma. The important consideration is that subjects are considered to be active searchers and not mere receptors of stimuli. In a way this is contrary to some usual procedures. Stretching the meaning of the word stimulus, it could be said that when a subject asks a question, he is selecting a stimulus. Ideally subjects should be able to generate themselves the questions they want to ask, but this would bring considerable experimental and methodological complications. In order to make the research operationally feasible, the choices that the subject can make should be restricted in number. This facilitates reproducibility and comparability of results at the price of reducing the spectrum of possible results. Approaches that eliminate this restriction have been used but they will not be duscussed here.

Our third assumption is that the observable tactics do in fact reflect in some manner the information that the subject searches, the process of evaluation of this information, hypothesis and hunches that he makes, the general approach he follows in order to attain a goal represented by the solution of the problem, etc. The same general considerations that were made concerning processes and tactics seem appropriate to discuss the correspondence between specific events in the process and specific events in the tactic.

In the fourth place we know that different tactics may lead to the same solution and thereby in terms of our assumptions we are entitled to assume that different processes may result in the same final solution. This casts a cloud on the usual procedure that "infers" processes from responses given to specific problems (either in experimental or life situations).

Our experience indicates that the variety of tactics is greater than the variety of responses. The doubtful procedure of classifying responses into limited groups of not always mutually exclusive categories reduces the possibility of finding out individual differences no matter how many tests are used or how many subjects are studied. Our approach in the study of cognitive processes began because of this difficulty, and the techniques that we have developed attempt to clarify in some way this issue. It is our experience (after gathering several tenths of thousands of protocols) that the technique that we use allows the emergence of styles of thinking and to estimate differences in this style more readily than the usual inferential approaches typified by many testing programs. Furthermore, if the interest of the experimenter is, in spite of everything, in knowing final answers, then the procedure that we are describing permits also the identification of these final answers.

These assumptions are a conf .ssion of our biases and ignorances. But by now it should be fairly obvious that our main interest is in the dynamic aspect of thinking processes rather than in their products. The results to be reported refer to observable tactics. A considerable part of our research was aimed and is aimed at designing instruments and research to reduce the uncertainty gap of the assignments made.

The Instruments Used and Some Methodological Considerations

The test of medical diagnostic skills developed in 1954 was the first application of the technique to a concrete situation (3).

It consists of a set of 3 x 5 cards on which a complete clinical history was transcribed so that on one card the patient's chief complaints were given, while on the remaining cards questions that the subject might want to ask were written. By picking up a card and looking on the reverse side, the subject can obtain the corresponding answer. The subjects were instructed to read first all the cards (all the possible questions) and afterwards to attempt a diagnosis of the case by picking up one at a time the questions (cards) that they desired and to look at the corresponding answer on the reverse side. The subjects were free to choose as many or as few cards as desired in the order they wished. The sequence of cards selected defines the subject's tactic. Changes that do not affect the basic characteristics of the technique can be introduced in the manner of presenting the information (for instance X-Rays films, actual photographs, etc.) or in the way in which the subject obtains the answer, like in the application of the technique in Part III of the National Board of Medical Examiners, and in several medical specialty boards (8).

The same technique was used to explore areas such as: diagnosis of Rorschach protocols, evaluation of therapy, problem solving of schizophrenics and of brain damaged subjects, problem solving of high school and college students, etc. The PSI (Problem Solving & Information) apparatus was an outcome of these early research efforts prior to 1960.

At the early stages, tactics were evaluated in terms of number of questions asked, type of questions and order (3). Utility indexes were defined for each question as a function of its frequency of selection by different samples of subjects. Statistics relating frequency of selection to order in the tactic were also described and performance curves were analyzed. The method of pattern analysis was formulated to deal with several aspects of the scoring problem (7).

This manner of evaluation is strongly dependent on the norms used. The same tactic would obtain different values if scored using norms obtained in physicians, or in senior or in junior students. Thus the same object (tactic) would have a different value according to the sample used as normative and this is a baffling problem. It seems that a valid measurement (score) should be formulated by defining subjects and instruments as independent.

Otherwise the same value, let us say x-grams, means one thing if the objects are made of wool, another if made of steel, or wood and so on at almost infinitum.

Thus our next line of research was concerned with developing instruments such that the obtained scores would depend on the property of the ruler used and on its specificity in measuring defined aspects of the phenomenon under examination. One possibility of doing this emerged when studying mathematical ability in elementary school children. It was found that complex logical mathematical concepts implied in certain well-known mathematical structures could be operated on by children if the problems were presented in languages with which they were familiar. For instance the Pythagorian theorem could be the structural bases for a problem presented in terms of every day objects and events.

In an early study entitled "A Program for the Study of Thinking", (9). we attempted to formulate how to differentiate experimentally between the logical structure of a problem and its manner of presentation (language). These two concepts are operationally independent within limits, though statistically considered, such independence may not always hold. As is always the case, independence should be formally demonstrated in each situation, though its assumption (whether verified or not) often simplifies experimentation.

The word "language" is understood as a collection of words, symbols, etc., with the condition that defined elements in the language correspond to defined elements in the logical structure. Thus the same logical structure can be presented in different languages, and different logical structures can be presented in the same language. Isomorphic problems are those that having the same logical structure as presented, are given in different languages, so that in more technical terms there is a one-one transformation relating corresponding elements in the languages.

In order to build a problem we decide first on a logical structure, then on the set of elements that will be given, and finally we make it concrete by expressing it in one or several languages.

The total difficulty of the problem is assumed to be a function of the logical structure (intrinsic difficulty) and of the language used (extrinsic difficulty). By definition, isomorphic problems will have the same intrinsic difficulty, though the total difficulty may vary from problem to problem as a result of the language used.

The tactics that the subject uses indicate how the subject deals with the logical structure of the problem and the scores assigned to tactics should reflect this aspect of performance.

A logical structure like the one presented in Figure 1 can be used to build several isomorphic problems. The symbol (T) refers to all the elements in the problem and this is usually presented when stating the problem. The symbol "?" corresponds to the answer that the subject has to find out. Knowing T, a and b, the solution can be obtained. If the problem is presented including questions d and c, then d and c together are defined as equivalent to a. The "ideal" tactic would be (a, b), a good tactic would be c, d, b, and so forth. In Table 1 examples of several isomorphic problems based on the structure of Figure 1 are given. For instance problem a is qualitative and is presented using drawings. In problem b, actual objects, in this case boxes, are used. Problems c, d, e and f are presented in written verbal language.

By selecting the questions that are presented with the problem, the experimenter can define, before any experimentation, the tactics that will lead to the solution. Relevant questions are those that provide information pertinent to the problem and irrelevant questions are those that do not provide pertinent information. Relevant questions can be classified into subclasses defined by the degree of generality that they imply. For instance in Figure 1, question a is more general than either c, d or b. The farther we move towards the right in the tree of Figure 1, the less general would be the corresponding question. An order reversal occurs when a specific question is asked prior to a more general question. Asking specific questions and the corresponding general question is a redundancy. For scoring purposes, specific questions are considered redundant independently of their sequential order with reference to the more general questions. We treat these redundant questions as irrelevant questions. Notice that a question is defined as redundant only in terms of the total tactic, so that a specific question is not redundant if the corresponding general question has not been selected.

After eliminating the irrelevant questions (pulling out) the remaining questions define the basic tactic; of these, the ideal tactic approximates the logical structure of the problem, it has no order reversals, and it isn't redundant.. The good tactics are those that though providing enough information for the solution of the problem, do have order reversals, and/or are redundant, etc.

A system of numerical indexes, consistent throughout problems, and based on the properties of the logical structures has been developed. These index values consider redundancy, reversals, irrelevancy and length of sequence. The schema pulling out method of scoring is computed using these definitions, and the experimental findings that I will report were obtained using this type of scores. Though we have experimented with uncertainty reduction scores, these results will not be presented here.

The type of scoring that we have defined is based on the logical structure of the instrument used and does not depend on sampling procedures. The definition of "measuring rod" does not depend on the subjects to which it is applied, but the values obtained do reflect differences between subjects. Clearly those scores can be treated using appropriate statistical operations.

Further, in terms of the operations performed, the obtained scores reflect specifically the process that the subject goes through in solving a problem. The function of language can be inferred by the differences in scores in isomorphic problems. An intriguing and perhaps important problem raised by these procedures concerns the element of time and order in the solution of logical structures. On this subject we intend to pursue further research. It is of interest to differentiate between scores based on group performance and those that we have just defined.

In Figure 2 are presented several matrices so defined that columns correspond to questions and rows to order. Assume that these matrices result from the performance of four different samples in which there is maximal covariance between questions and order, so that all the subjects in each sample do exactly the same. These four samples define four sequences, that is: 1) b,a,d,c, 2) d,c,b,a, 3)b,a,c,d, and 4) a,b,c,d. Assuming that the ideal sequence of the problem is d,c,b,a, then any subject following this sequence would obtain a low score if the norms used correspond to the sequences 1, 3, or 4 above. That is, in spite of the fact that these sequences represent maximum agreement, a subject following the "best" sequence would obtain a low score. The point that we want to make relates to the fact that agreement or popularity of response is not evidence of "better" performance and that these concepts ought to be clearly differentiated. In terms of our pulling out scores, the values obtained may be low and the subjects of the sample agree in being "wrong". As a matter of fact agreement does not necessarily make for less ignorance. Using the concept of uncertainty, it is possible to characterize agreement in tactics. This we have done systematically but the results will not be reported here. In the studies to be reported we have evaluated subjects both in terms of the schema pulling out score and in terms of agreement in tactics.

Some Experimental Results

In several studies we sought to differentiate experimentally logical structures and language. These efforts ran parallel to sharpening the properties of our instruments and our scoring procedures. The possibility of isolating these components of a thinking process was sketched over 20 years ago (2), though at that time we did not have the appropriate instruments to test these two variables.

Recently (4) we suggested the following definition: in a restricted sense, thinking can be understood as an attempt to make explicit and communicable (to one's self or to others) the formal properties of a problem. Notice that the subject may or may not be aware of the logical structure of the problem, but still his performance may indicate how he deals with it. Further we differentiated one-one and not one-one, and onto and not onto languages.

Languages approaching the onto property as opposed to those of a non-onto character are those by means of which more logical structures can be expressed. One language that seems to approach the onto property is the ordinary verbal language, by means of which almost all logical structures can be expressed. The languages in current usage may differ in their onto property. But an onto language may not be one-one, in the sense that one and only one unit in the language might not correspond to one and only one unit in the logical structure which, of course, introduces uncertainty. On the other hand certain languages may be one-one though the logical structures that can be expressed may be fewer in number than what is the case with the onto languages. These one-one languages though precise may be non-onto. This would be the case of certain abstract symbolic languages by means of which high precision is attained though the structures that might be expressed with them are limited in number.

To test some of these hypothetical experimental considerations, we administered 20 problems to 150 subjects between 18 and 22 years of age. Out of 20 problems, 16 were built around four logical structures, structure 31 (a tree with a double dichotomy, as shown in Figure 1), structure 33 (a dichotomy and a trichotomy), and structure 35 (a tree with with trichotomies). Structure 60 consisted of a dichotomy and a trichotomy, as shown in Figure 3 but some branches converged towards the right. For each structure, four isomorphic problems were built using: A (verbal language), B (abstract symbolic language), C (negative abstract symbolic language) and K (concrete geometrical drawings). The problems are identified as 31A, 31B......60K. The four remaining problems were of a different type and will not be discussed here. The factor analysis of the tactic scores gave a clear oblique simple structure as indicated in Table 2.

Of the 7 factors, 5 are readily interpretable. Factor B includes exclusively all the problems presented in K language (concrete geometrical drawings), regardless of logical structure. Factors A and E have a high correlation among themselves (+.52) and seem to be defined by the B and C languages (abstract and negative abstract). While factor E is defined by structure 31, factor A includes both structures 33 and 35. It is possible that the relative greater complexity of of structures 33 and 35 by comparison to structure 31 is here influential in defining factors A and E. On the other hand the common language that appears to both factors may generate the previously reported correlation. It is extremely intriguing that factor C is defined by structure 60, in all languages but K since problem 60K contributes to define factor B. It should be remembered that problems of the series 60 correspond to structures with some unique features as described above. Factor D includes problems presented in verbal language throughout different logical structures, and this tends to be of the onto type. The results seem to indicate that languages K (concrete) and A (verbal) run through a larger variety of logical structures, perhaps at the risk of being less precise than languages B and C.

It is unavoidable for us to suggest that this type of experimental results is pregnant with possibilities; for instance, the interplay of language and logical structure in the development of knowledge and science or for a more concrete and applied example, the changes of these variables through maturation and education, pathological changes, etc. We are now completing a 5 year longitudinal study with children between 7 and 12 years of age, where this problem will be further explored. In terms of these results it seems appropriate to say that if a subject is able to solve a problem in any one of all the possible languages in which it may be given, then the subject can operate with the logical structure implied in the problem. This provides a way of testing logical structures at different ages. Recently it was found that prelingually deaf children between 6 and 8 years of age did solve problems as well as normal children, provided these problems were presented using drawings (11).

In another study we explored the tactics used by subjects between 9 and 79 years of age when solving problems built around structure 31 presented in verbal and abstract languages, as shown in Figure 4. The curves are parallel so that from an average age of approximately 10 to 13 and up towards the older ages, the B language (abstract-symbolic) always gives a lower score than the A language (5).

Finally in an earlier research (6) we studied children of 7, 9, 11 and 13 years of age (30 subjects per age group). Six problems were administered to them except at age 7, when only three non-verbal problems were given because some of the children could not read properly.

Both problems A and B were presented using wooden blocks of different colors (red and blue) and drawings (circles and squares) as can be seen in Figure 5. The subject had to find out how many objects were inside the red circle portion in block X. The verbal form of problem A was problem V_1. In problem B, blocks R and BC were not given. Problem V_2 was isomorphic to problem B. The structure of problem C consisted of a dichotomy (red and blue) and a trichotomy (circles, squares and triangles) and was presented using blocks as shown in Figure 6. Problem 31A was verbal and included two dichotomies.

As indicated by Figure 7, it is clear that the solution of problems A, B and C improves with age. In the case of problems A and B, the improvement is especially noticeable between 9 and 11 years of age. The improvement with age when using a more complex structure like in problem C is more progressive. The difference for successive ages were in all cases significant. The lack of parallelism between the curves corresponding to problem C and those of problems A and B, suggest an interaction between age and logical structure as presented in these problems.

The isomorphic problems A and V_1 do not show interaction between age and language though there is a significant improvement (.01 level) due to age as shown in Figure 8. But with the isomorphic problems B and V_2, there is significant improvement with age, as well as a significant interaction (.01 level) between age and language as indicated in Figure 9. Notice that between age 11 and age 13, the scores in the problems using verbal language (problem V_2) increases more than when the manner of presentation is made using colored wooden blocks.

Remembering that problems A and V_1 and B and V_2 differed only because in problems B and V_2 the number of possible choices were reduced, the problems B and V_2 may be considered to be more "complex" than problems A and V_1. It is interesting to find out that no interaction between age and language was found for problems A and V_1, but that such interaction occurs in the case of problems B and V_2, with the verbal language increasing more rapidly than the concrete language (problem B).

Summarizing: it seems that in cognizing cognitive processes a clear differentiation should be made between the contribution of language and logical structures, since these two components have apparently a definite function in cognition. Scoring tactics provides information that is not usually obtained in current testing operations. It also brings into the foreground the element of time and order in logical structures. The development of these logical structures and of language in terms of their onto and one-one property seems worth exploring. The implications may well extend into other areas as we are now observing in relation to autonomic variables, personality and perceptual factors, memory, etc.

TABLE 1

Problems	Information Given (T)	Statement of Problem and Solution	Question (a)	Question (c)	Question (b)
a	There are big boats and small boats. Some are white and others are blue.	Which type of boat was chosen? Solution: A small white boat.	Is it a big (either blue or white) boat? No.	Is it a big blue boat? No.	Is it a small blue boat? No.
b	There are round and square boxes which are also either red or blue. There is a total of 50 objects in these boxes.	How many objects are there in the round red boxes. Solution: 15.	What is the number of objects in the square boxes (both red and blue)? 20	What is the number of objects in the square blue boxes? 10	What is the number of objects in the round blue boxes? 15
c	There are 30 students, both boys and girls, who are studying English and mathematics.	How many boys are studying mathematics. Solution: 5.	How many of the students are girls? 10	How many of the girls are studying English? 5.	How many of the boys are studying English? 15.
d	There is a total of 20 objects called A's and B's. The A's are either C's or D's and the B's are either C's or D's.	How many B's are also D's? Solution: 8.	How many A's (both C's and D's) are there? 10.	How many A's that are also C's are there? 5.	How many B's that are also C's are there? 2.
e	Problem "e" is similar to "d" but it uses negatives.				
f	There is a total of N objects. These can be either A's or B's. The A's can be either C's or D's amd the B's can be either C's or D's. N' = P + Q = B + M + Q	How many B's are also D's. Solution: N-P-F	How many A's are there? P.	How many A's that are also C's are there? S.	How many B's that are also C's are there? F.

TABLE 2

Factor Analysis of 20 Cognitive Problems

	A	E	B	C	D	F	G
33B	+						
33C	+						
35B	+					+	
35C	+						
31B		+					
31C		+					
43		+					
31K			+				
33K			+				
35K			+				
60K			+			-	
60A				+			
60B				+			
60C				+			
31A					+		
35A					+	+	
43A					+		
44					+		
33A						+	+
40						+	+

+ indicates loadings higher than +.25

- indicates loadings less than -.25

Figure 1

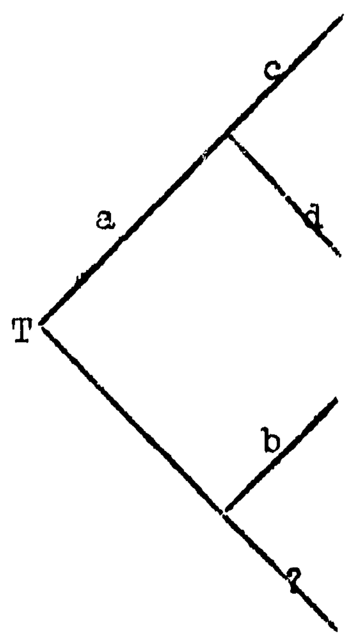


Figure 2

Questions

Order	a	b	c	d
1		X		
2	X			
3				X
4			X	

Questions

Order	a	b	c	d
1				X
2			X	
3		X		
4	X			

Questions

Order	a	b	c	d
1		X		
2	X			
3			X	
4				X

Questions

Order	a	b	c	d
1	X			
2		X		
3			X	
4				X

Figure 3

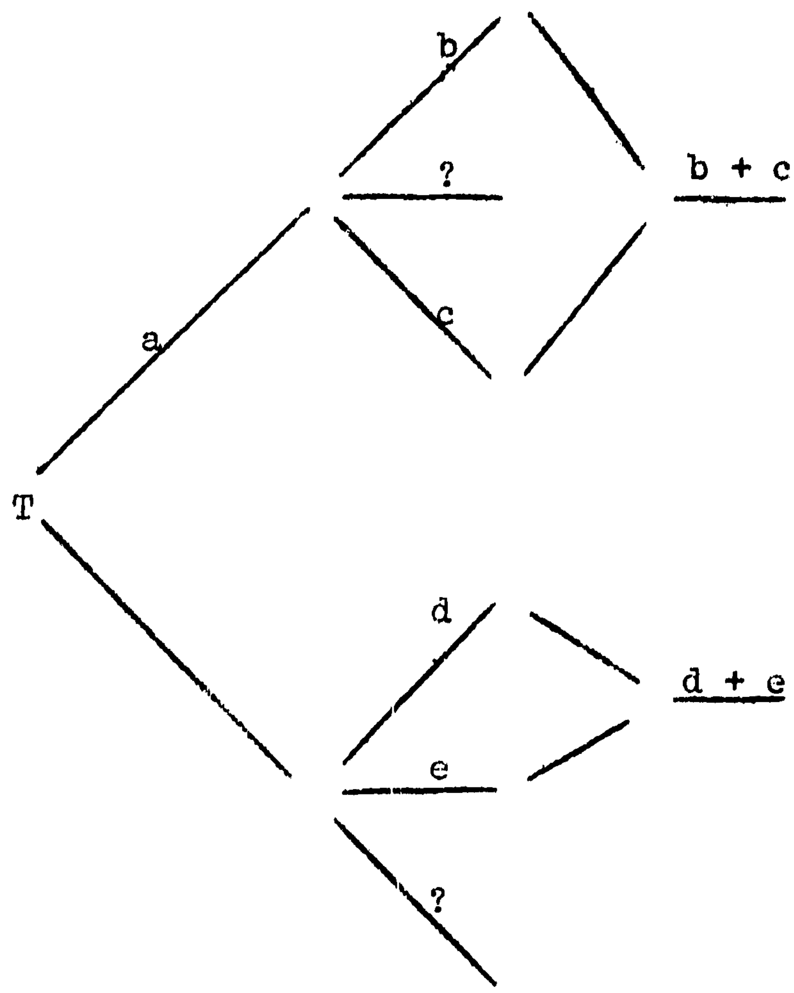


Figure 4

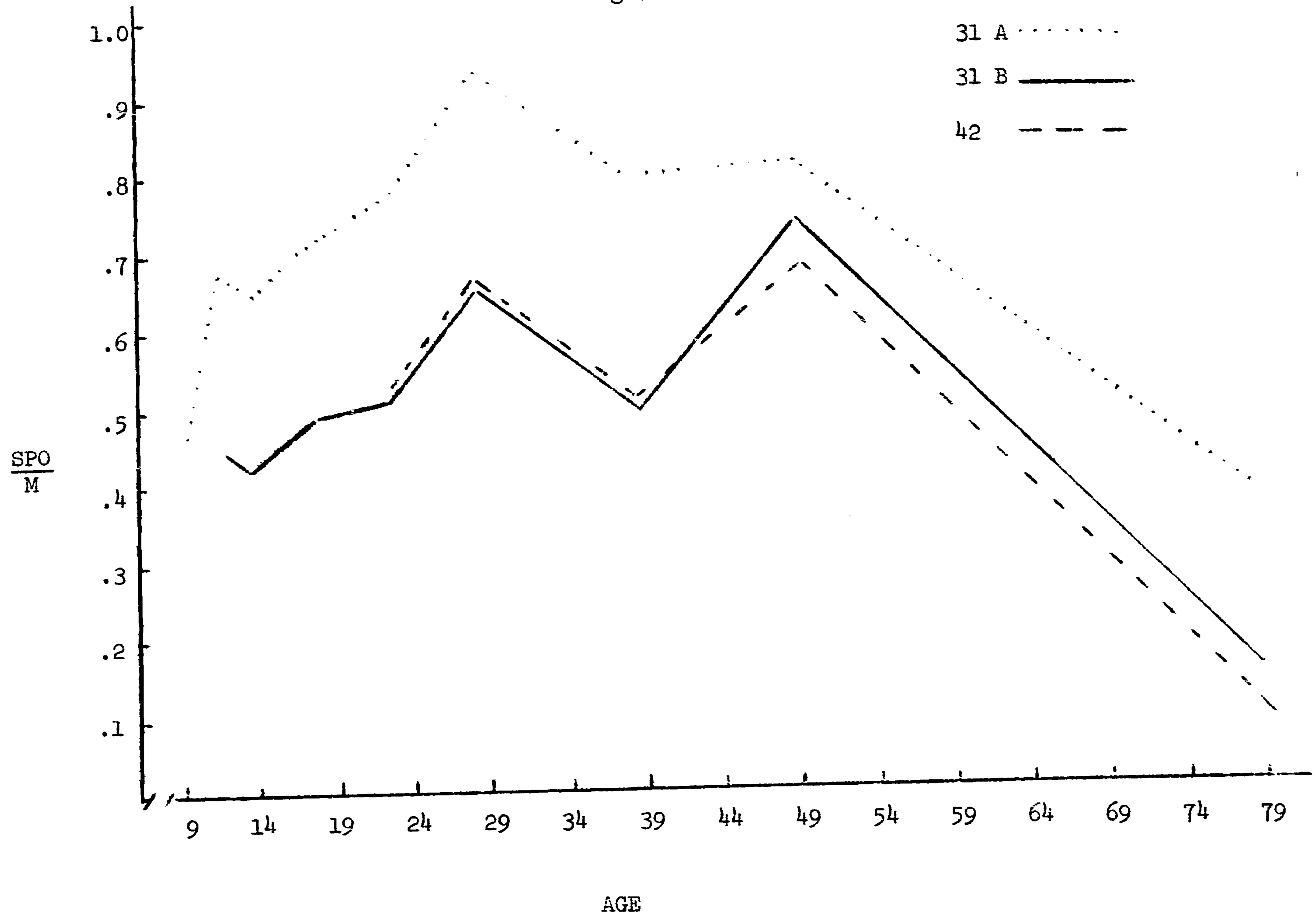

31 A
31 B
42
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
SPO/M
9
14
19
24
29
34
39
44
49
54
59
64
69
74
79
AGE

Figure 5

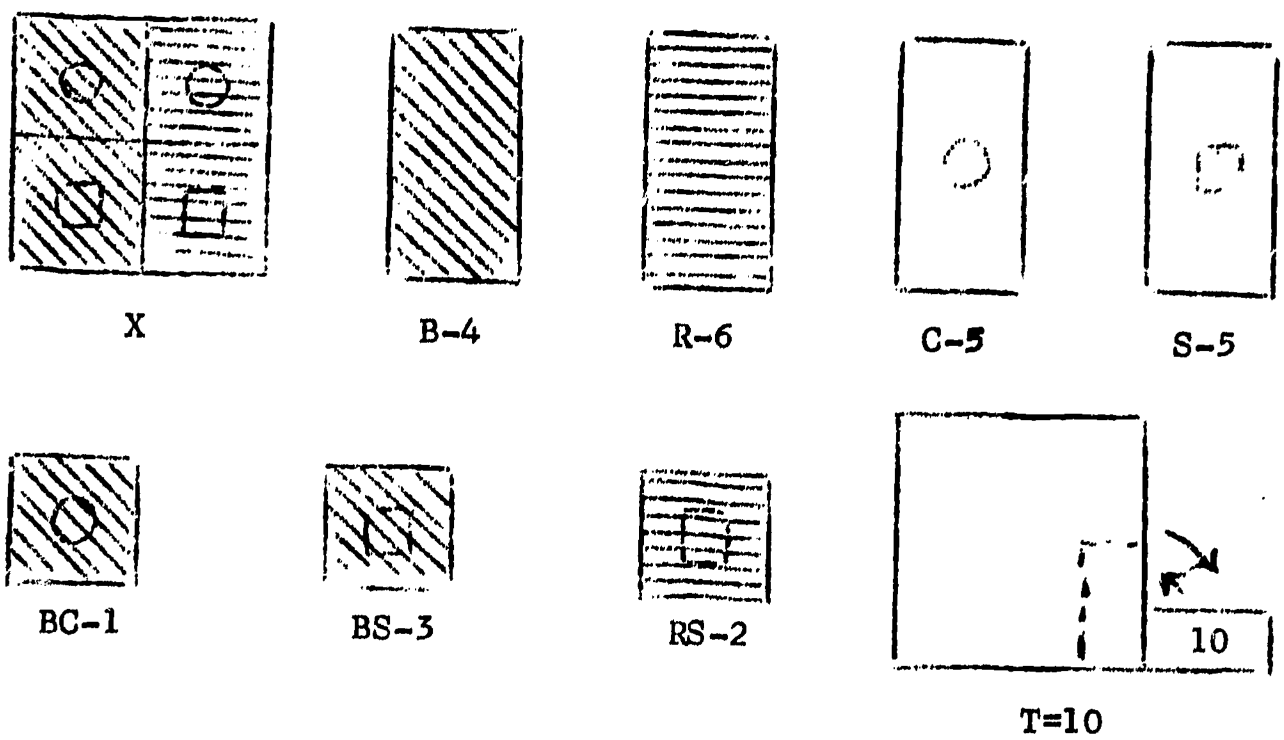


Figure 6

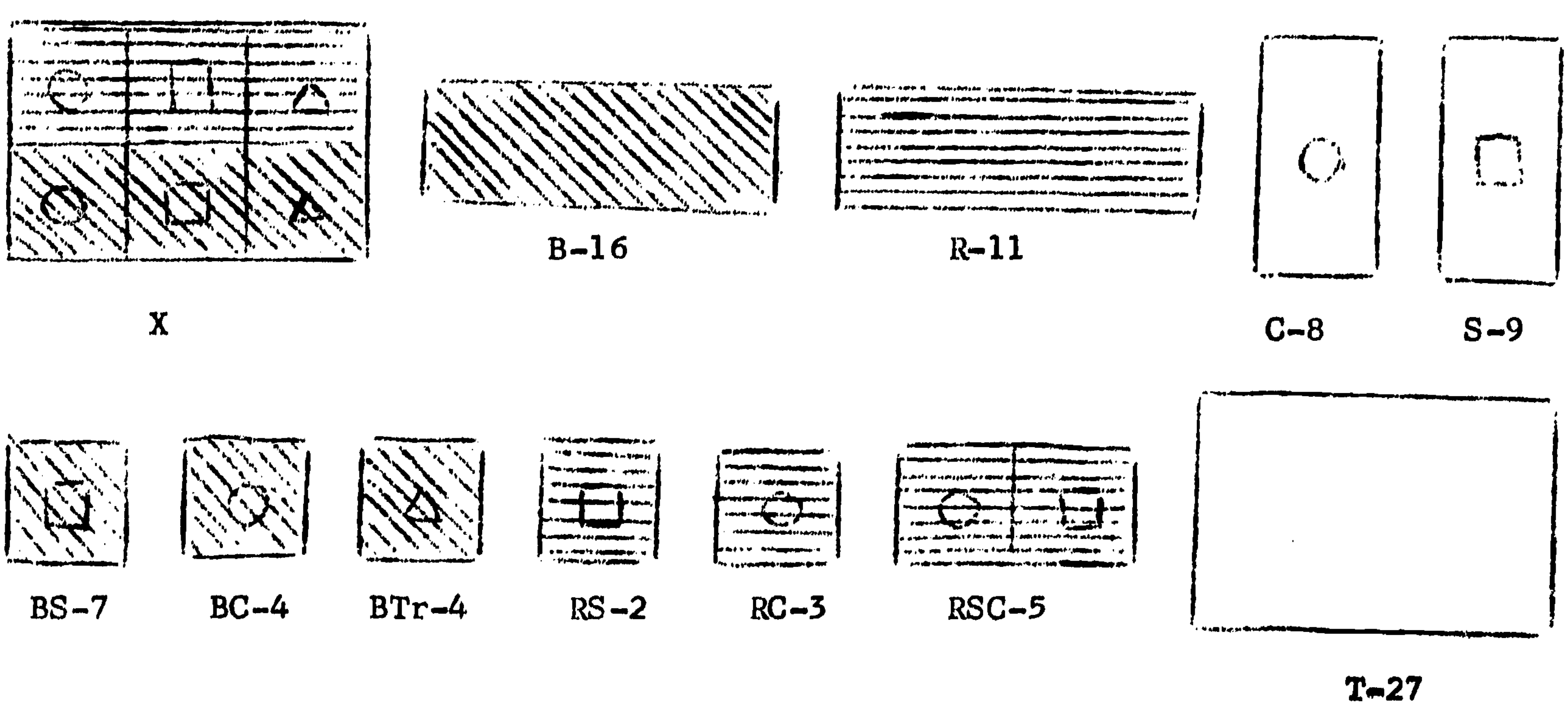


Figure 7

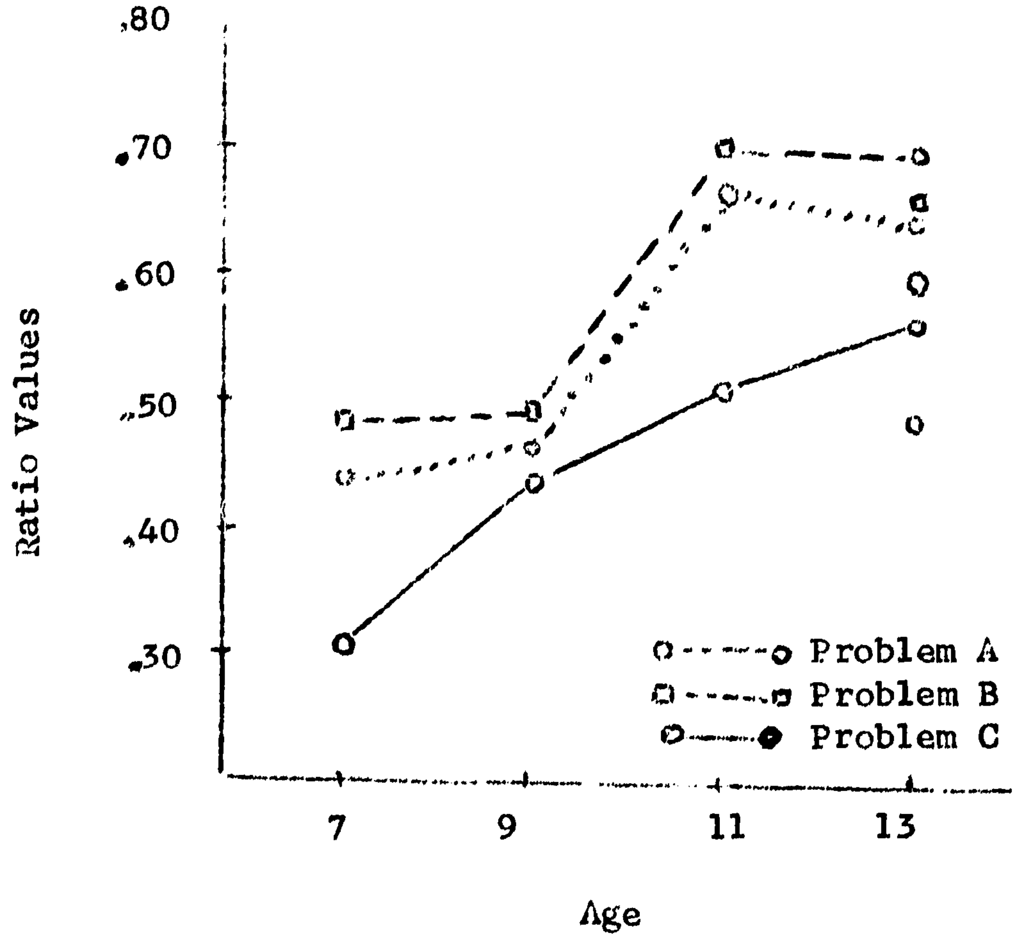


Figure 8

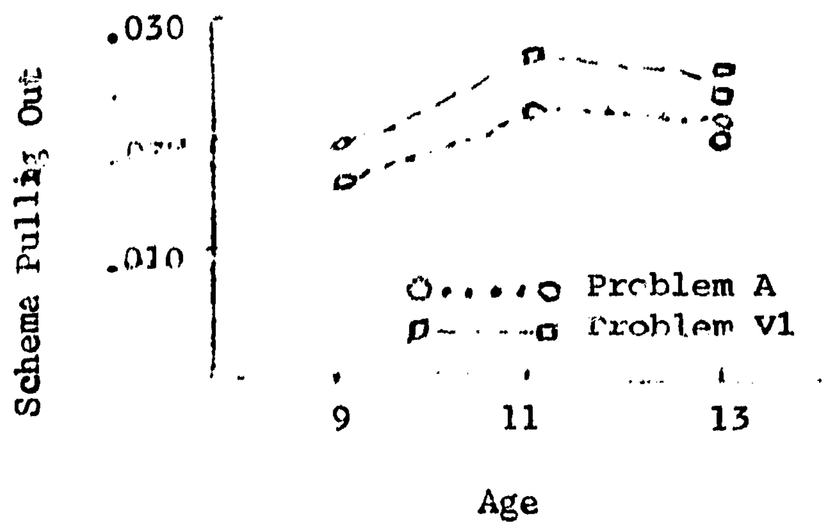
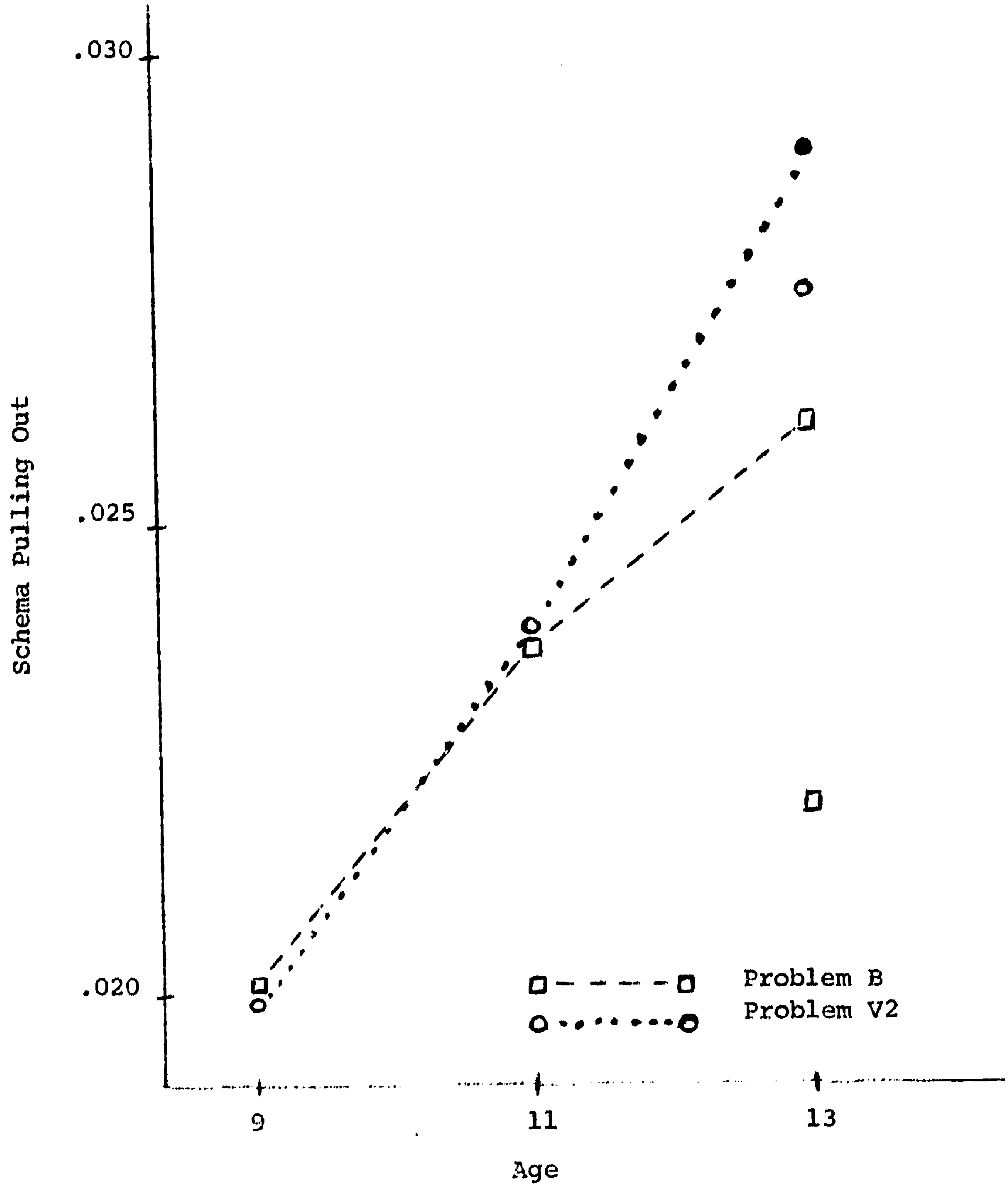


Figure 9


.030
.025
.020
Schema Pulling Out
Problem B
Problem V2
9
11
13
Age

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