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ABSTRACT

The first part of this paper briefly describes two studies concerned with cognitive processes in children. One study examined the ability of Kindergarten and First Grade children to apply a simple rule of logical inference in order to solve a two-object discrimination problem. Specifically, the rule was of the form "if A, then not B." A second study employed the more difficult conditional discrimination problem and provided evidence concerning the ability of pupils in Grades 6, 10, and 14 to apply the more complex rule "if A and B, then A; if B and C, then B; if C and A, then C." The second part of this paper describes preliminary efforts to develop a general model for describing cognitive processes. The proposed model was compared to other similar theoretical models. Finally, the practical usefulness of this theoretical model for educational research was demonstrated by describing a successful elementary school mathematics project which stressed the analysis of mathematical statements into statements of underlying cognitive operations of processes. (Author)

TOWARD A GENERAL MODEL FOR DESCRIBING COGNITIVE PROCESSES

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CENTER FOR COGNITIVE LEARNING

Theoretical Paper No. 23

TOWARD A GENERAL MODEL FOR DESCRIBING COGNITIVE PROCESSES

By Harold J. Fletcher
(Now at Florida State University)

Terminal Report from the Rule Learning Project
Harold J. Fletcher, Principal Investigator

Wisconsin Research and Development
Center for Cognitive Learning
The University of Wisconsin
Madison, Wisconsin

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The Wisconsin Research and Development Center for Cognitive Learning focuses on contributing to a better understanding of cognitive learning by children and youth and to the improvement of related educational practices. The strategy for research and development is comprehensive. It includes basic research to generate new knowledge about the conditions and processes of learning and about the processes of instruction, and the subsequent development of research-based instructional materials, many of which are designed for use by teachers and others for use by students. These materials are tested and refined in school settings. Throughout these operations behavioral scientists, curriculum experts, academic scholars, and school people interact, insuring that the results of Center activities are based soundly on knowledge of subject matter and cognitive learning and that they are applied to the improvement of educational practice.

This Theoretical Paper is from the Rule Learning Project in Program 1. General objectives of the Program are to generate new knowledge about concept learning and cognitive skills, to synthesize existing knowledge, and to develop educational materials suggested by the prior activities. This project focused on rules or descriptions of logical operations used in solving simple problems, with the long-range goal of relating a taxonomy of general classes of rules and their use to similar analyses of other cognitive skills used in school learning.

PREFACE

The writer wishes to express his gratitude for the invaluable contributions made to this project by his assistants, Mrs. Jeri Grogg and Mrs. Annette Joslyn, and his students, Gretchen Freiheit, John Garske, Tom Grogg, Joseph Kemmerer, and especially, Douglas Sawin, for his able assistance in developing the general model described in this report.

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INTRODUCTION

Initially, this project was concerned with conducting relatively restricted laboratory-like experiments designed to provide information on the ability of school-aged children to solve tasks involving selected cognitive rules. All experiments were considered with respect to the following criteria: First, the emphasis was upon cognitive rules, or operations, in order to complement Professor Klausmeier's project which emphasized the acquisition of concepts; second, there was promise of programatic research in an area not already well researched; third, the acceptable rigorous experimental methodology of S-R learning theory was adapted in ways which permitted controlled investigations of more interesting cognitive aspects of learning; a fourth criterion required the research to be developmental in nature, i.e., not restricted to one age group; and finally, the rules investigated were selected because of a rather obvious relation to, hence implication for, a learning situation which takes place in the classroom.

The overwhelming problem of synthesizing the research-revealed psychological knowledge and determining its relevance for education became unmistakingly clear from the writer's experience in the Wisconsin Research and Development Center. In his role as director of Program 1, the writer recognized the need for some global model, theory, organization, or taxonomy which would serve to reveal the interrelationships of independent research projects and provide a language or system for extending experimental findings to actual pedagogical problems. Moreover, USOE officials (in particular, Professor Francis Chase) continually emphasized the need for such integrative attempts. Consequently, the personnel on this project began a fairly ambitious attempt to review existing literature with the goal of selecting or deriving a general model for describing the general cognitive operations or processes which underly the specific behaviors of interest in education. Two results were anticipated. First, the model would serve to reveal more clearly the specific contribution of independent research projects by indicating the precise type, or level, of cognitive ability being investigated. Secondly, the model would serve as a convenient system for a task analysis of any particular subject matter, the result of which is a more tractable specification of a pedagogical problem. The intended schedule called for (1) an examination of existing general models such as Bloom's Taxonomy and Guilford's structure of intellect model, (2) an enumeration of cognitive abilities measured by mental tests (and indicated by factor analyses to be independent), and (3) a review of subject matter analyses such as the American Association for the Advancement of Science (AAAS) analysis of Science in elementary school.

Unfortunately this project terminated prematurely in August 1968 because the writer accepted a position at the University of Rochester. Consequently, this cannot be a final report of goals achieved; it is a progress report of unfinished work. Where possible, important experimental results and their implications for education will be discussed. The writer's primary intention, however, is to record ideas which had promise and strategies which seemed fruitful so that others may, if interested, continue this work. This report will consider first the results of experiments, next the progress made toward deriving a general model, and finally some thoughts on implications for education.

II
RESULTS OF EXPERIMENTS

Since Aristotle, formal logic has invited the scrutinizing stares of philosophers and mathematicians. Of the many who attempted to develop a system for describing logic, we are perhaps most indebted to the mathematician, George Boole, who, over 100 years ago symbolized the verbal descriptions of logic and gave birth to what is known as Boolean algebra of sets. Essentially an algebra of classes, or class logic, Boole's sytem has been supplanted by modern propositional calculus. Both systems, however, are designed to discuss truth statements and their connectives, such as "if..., then...." Logically it matters not whether the statements are completely verbal (such as in the tired syllogism, "All men are mortal...,") or completely symbolic (p⊃q, or p implies q). It is assumed that the same "laws of thought" or cognitive rules are involved. Most elementary textbooks on formal logic use the familiar Venn diagrams to describe the binary relations of Boolean set algebra or propositional calculus. Moreover, modern elementary—in fact, beginning—mathematics texts employ set theory and modified Venn diagrams to introduce the rules underlying mathematics.

Evidently, then, the rules of formal logic are becoming quite explicitly involved in the learning of at least elementary arithmetic despite a lack of any basic research on children's ability to apply these kinds of cognitive rules. It seemed appropriate, therefore, to begin a program designed to investigate the child's developing capacity to apply the rules of logical inference.

First it was necessary to identify the simplest form of logical inference and the appropriate task and methodology for empirical investigations. Within a binary context, the most primitive rule is of the form "If A, then B", i.e., straightforward implication or logical inference. A common binary laboratory task is the typical second-choice discrimination task in which the subject has only to discriminate the Positive (P) stimulus from the Negative (N) stimulus.

Unfortunately, most discrimination learning research is irrelevant because the methodology usually employed is designed to allow tests of simple associationistic S-R learning theories and not higher order cognitive processes. For example, the trial-and-error technique is conventional and any learning which takes place is most parsimoniously attributed to the development of approach tendencies following rewarded responses to the positive (P) stimulus and separately to avoidance tendencies following nonrewarded response to the negative (N) stimulus. Yet the structure of the task is such that on each trial the subject can learn about both stimuli, one as a result of direct experience, the other by inference. Because only one stimulus is rewarded, a subject can, for example, use the rule "If P, then not N" (or the converse "If not N, then P") to learn about both the responded-to stimulus and the nonrespondeo-to stimulus.

Clearly, though, the conventional methodology had to be modified in order to investigate the possibility of logical inference taking place in the simple discrimination task. In a number of unreported pilot studies the necessary procedures were validated. Two final experiments are reported in detail elsewhere (Fletcher & Garshe, 1968) and will be discussed only briefly here. Essentially, a prompting technique was employed to control S's response to only P of a P+N pair on a number of training trials. On a subsequent nonprompted cue-substitution test trial a new stimulus X was paired with the old N and S was given a choice. If learning (as most association learning theory would suggest) was restricted only to the previously displaced P, then S would know nothing about either X or N and performance would be at chance on the X+N test trial. But if S had in fact inferred the nonreward value of N while previously displacing the prompted P, he would avoid N and select the new X stimulus. Other control conditions, P+N and P+X test trials, were included to measure and take into account any possible novelty artifact.

The problem can be described with Venn diagrams. Figure 1 depicts the situation in which it is assumed that S learns nothing about the nonresponded-to N during prompted trials. The three circles indicate the learned value of each stimulus; the three overlapping circles represent the three types of nonprompted test trials; and the intersections of each pair of circles contains the appropriate solution rule. For both the P+N and P+X case, the rule is simple affirmation, i.e., "P is correct." The intersection of X+N is empty, indicating no solution rule based upon previously learned differential values of either N or X.

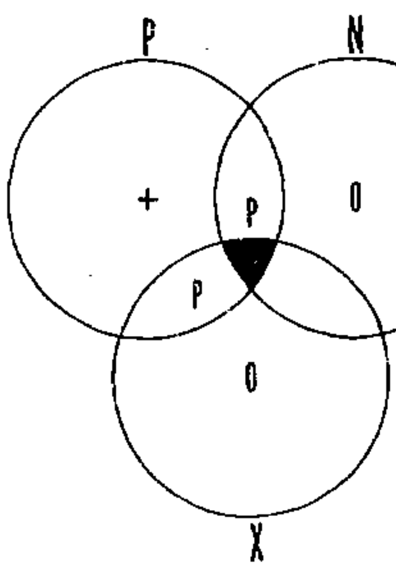

FIGURE 1. Schematic representation of the case in which the subject does not infer the negative value of N while responding to the positive P during prompted trials.

In Figure 2, however, it is assumed that S had made the inference that N was nonrewarded and had therefore learned the values within each circle. The intersection of X+N in this case does contain an appropriate solution rule, i.e., "not N", and above-chance performance is predicted.

The results indicated that Kindergarten and First Grade children were significantly above

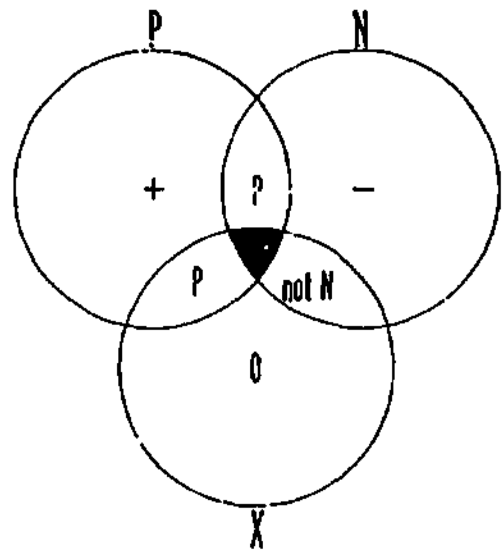

FIGURE 2. Schematic representation of the case in which the subject does infer the negative value of N while responding to the positive P during prompted trials.

chance on the critical X+N trial. Verbal reports, moreover, confirmed the assumption that the Ss were choosing X because they at least "knew that N was wrong." They were therefore inferring additionally that the X was probably correct.

It is interesting to note here that identical experiments conducted independently by the writer with retardates with mental ages similar to those of First Grade children and with test-sophisticated monkeys revealed that the retardates were also significantly above chance on the X+N trial, but the monkeys were not.

At a minimum, therefore, these results indicate that young children (and retardates) do simultaneously process information about both stimuli of a known binary task. While it may be possible to stretch S-R learning theory to handly these data, the writer prefers to interpret these data as evidence for the ability to apply the simple logical rule "if A, then not B." Moreover, the failure of sophisticated monkeys to solve the same problem suggests that this ability may be unique to the human primates.

It must be emphasized, however, that performance on X+N trials was only approximately 70% correct for these children, and while this was significantly above chance, this level of performance clearly cautions against the assumption that all children enter elementary school with a ready facility for applying even this simple rule of logical inference. The writer feels that children should be first tested for, and perhaps trained on, this type of logical inference before they are given arithmetic Problems which involve this cognitive rule. A second experiment (see Fletcher, et al., 1968) essentially replicated and confirmed these findings.

Another line of research pursued a more complex "if..., then..." rule. This research (see Grogg & Fletcher, 1968) sought and found a problem which required for its solution a response not to separate stimuli but to the relation between the stimuli. In the learning literature this type of problem is referred to as the conditional discrimination. One form, the non-sign-differentiated (NSD) problem involves three pairs of stimuli: A+B in which A is rewarded; B+C in which B is rewarded; and C+A in which C is rewarded. Thus, over any series of trials (with each pair occurring equally often) each element, or separate stimulus, is equally positive and negative. Solution, therefore, is impossible in terms of simple affirmation of element values. A correct solution demands that S note the relationship between both stimuli and employ the rules: "If A+B, then A; If B+C, then B; If C+A, then C." This NSD problem, too, may be depicted with Venn diagrams. In Figure 3, there is no absolute value indicated in the circle for each stimulus because each has a unique value only in relation to the other stimulus with which it is paired on a particular trial. Thus, the intersections of the three pairs indicate the rule, or logical implication, which must be learned in order to respond correctly to each pair and solve the problem.

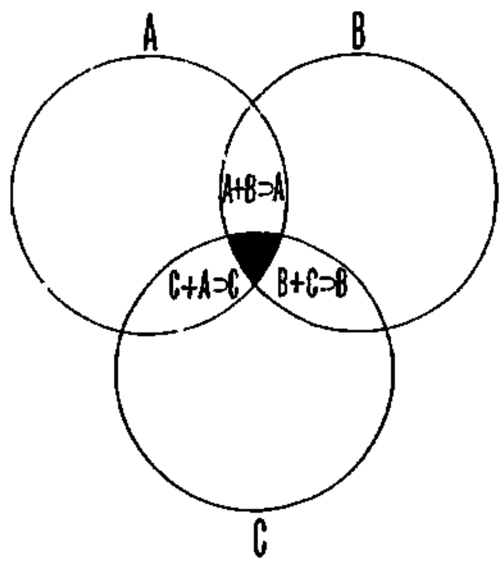

FIGURE 3. Schematic representation of the non-sign-differentiated (NSD) conditional discrimination problem.

A second form of this problem, the sign-differentiated (SD) conditional discrimination problem, is conceptually simpler when analyzed in terms of its solution rules. Structurally similar to the NSD problem, the SD problem involves an additional cue (e.g., color) on each of the three trials or pairs. Thus, both A+B stimuli may be red; B+C may be green; and C+A may be blue. The SD problem, depicted in Figure 4, clearly requires a simpler solution rule (again given in the intersections) for each pair. In fact, because of the additional cue of color the rule is simple affirmation in each case. For example, S must merely learn "red A is correct; green B is correct; and blue C is correct." It is important to note, therefore, that it is not at all necessary to consider the relationship between any two stimuli, or even to attend to both stimuli, on any trial in order to solve the SD problem. However, one can ignore the color cue and employ the same more complex rule required in the NSD Problem.

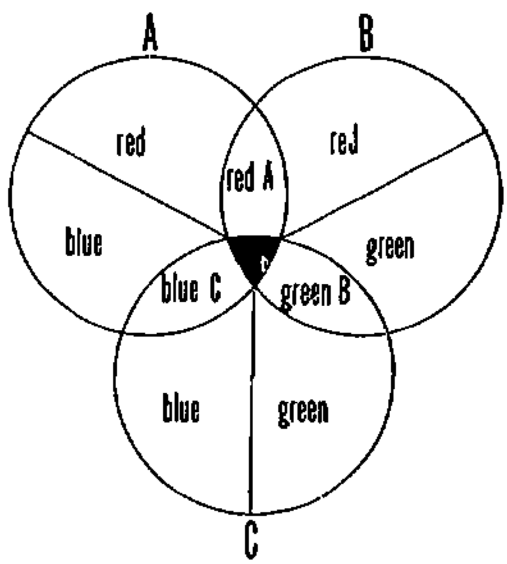

FIGURE 4. Schematic representation of the sign-differentiated (SD) conditional discrimination problem.

Both an SD and NSD problem were included in this study in order to confirm empirically the theoretical differential difficulty. Preliminary pilot investigations indicated the futility of testing young children on NSD Problems. Hence, Sixth Graders, Tenth Graders, and college Sophomores were tested.

As expected, the NSD problem was considerably more difficult than the SD problem for all age groups and performance on both problems increased monotonically across all age groups. In addition to the choice data, all Ss were questioned in order to determine what kind of solution rules were employed. Only 25% of the Sixth Graders were able to express the appropriate relational rule for the NSD problem; 45% of the Tenth Graders did so; and 53% of the college Sophomores accurately verbalized the "if..., then..." rule. Moreover, in solving the SD problem (which again could have been solved with either the simple affirmation rule or the more complex relational implication rule), 5%, 10%, and 16% of Sixth, Tenth, and Fourteenth Graders, respectively, spontaneously utilized the relational rule, while 20%, 45%, and 69% reported using the simpler affirmation rule.

These results reveal a rather limited general ability of Ss to detect, encode, and retain conditional relationships in solving problems. Indeed, the fact that only 25% of Sixth Grade children displayed this cognitive ability points to the need for greater assessment of fundamental cognitive abilities in elementary school children.

In summary, these experiments were initial attempts in a program designed to investigate the developing ability of children to apply cognitive rules in solving problems. The research established two laboratory-like tasks for investigating two fairly simple rules of logic. Performance on these tasks did reveal developmental trends, i.e., increasing ability to solve the tasks, but on neither task was performance very impressive. Indeed, in all experiments the majority of younger children did not reveal a ready facility with the rules investigated, and it seems evident, therefore, that more of this kind of research is needed.

It is the writer's opinion, however, that while these "demonstration experiments" are useful, the most productive type of research is that which attempts to explain the causes of poor performance by first revealing the specific cognitive operations involved in each task and then by isolating the faulty operation. For example, in the NSD problem S must attend to both stimuli, encode the stimuli as relationships, store and recall the relationships, and finally compose the solution rule. A S may fail a particular task not because of an inability to perform the last step but because of failure on some preliminary step. If the ultimate goal is the improvement of performance on certain tasks (as it certainly is in the classroom), then it seems obvious that what is needed is both a general theoretical model for analyzing tasks into component abilities and the kind of research which reveals optimum training procedures for each ability.

For the above reasons, experimental efforts were temporarily terminated and, instead, a review was made of existing general taxonomies of cognitive skills, theories, or models, in hopes of finding, or developing, one useful model for guiding future research.

III

TOWARD A GENERAL MODEL OF COGNITIVE PROCESSES

In order to facilitate a general consideration of cognitive processes, it was first necessary to catalog and analyze tests which apparently assess independent processes, or abilities, especially those tests developed for testing school-aged children. To this end five common tests were reviewed: the Stanford-Binet Intelligence Scale; the Wechsler Intelligence Scale for Children; the Wechsler Preschool and Primary Scale of Intelligence; the Arthur Adoption of the Leiter Scale; and the Kit of Reference Tests for Cognitive Factors. Most of these tests contain similar items, and thus for convenience we focused primarily upon the tests found in the last-mentioned Kit (French, Elstrom, & Price, 1963). In their attempt to validate Bloom's Taxonomy, Kropp & Stoker (1966) also relied upon the Kit tests.

Next, the taxonomy of Bloom (1956) was examined. Bloom attempted to compose a heirarchically arranged descriptive model of cognitive factors which are directly relevant to student behaviors. As such, the model retains generality at the cost of precision, and it requires much interpretation and translation to handle specific situations.

By far the most ambitious—and successful—effort to devise a general system is that of Guilford (see especially Guilford, 1967). His Structure-of-Intellect (SI) model, developed gradually during years of intensive factor analytic studies of intellectual abilities, is a morphological taxonomy (i.e., a logical matrix) of independent elements. His matrix is [currently] three-dimensional with operations orthogonal to products and contents, all of which define unique intellectual factors. The logic underlying the structure of his matrix comes from results of the factor analysis approach. Although Guilford argues persuasively that the intellectual skills are in fact different depending upon what contents and products are involved, we considered it necessary to ignore temporarily this distinction and to consider only his operations in an initial formulation of general cognitive processes. Parenthetically, Guilford does seem to have trouble with classifying "transformations" as a product rather than an operation.

For two reasons, our preference was for an operational model, i.e., a computer-like model which depicts information flow. First, it seemed that each test (or task) is best differentiated with regard not only to the processes involved but also with regard to the sequence of the operations. Secondly, a schematic representation emphasizing processes [calls attention to the degree to which the processes] have in fact been described [or not described]. Therefore, we first composed for a large number of the kit tests a separate flow diagram of operations or processes presumed to be involved in solving the particular test. These flow diagrams were then all examined in order to derive a general descriptive model.

A first approximation to this general model is given in Figure 5 which indicates four functional stages of information processing. In this form, the model is merely descriptive; and the actual functions of each stage must be described in detail in order to reveal the similarities and differences between this and other models of cognitive processes.

In general, each stage involves rule-governed processes, the specific processes invoked being dependent upon stimulus constraints, past experience, specific instructions or training procedures, and probably some experientially determined heirarchy of preference.

STAGE I. Attentional Processes

This stage includes all processes which serve to detect those cues which are relevant to the particular problem. Generally, it is assumed that S has these requisite abilities, although good training techniques assure the assumption

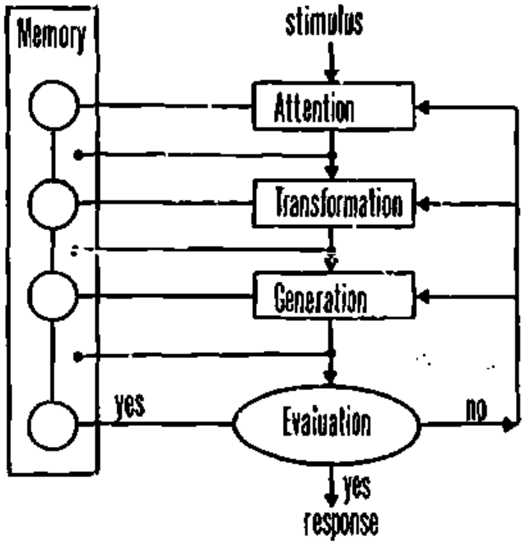

FIGURE 5. Schematic representation of a general operational model of information processing with four functional stages of cognitive processes.

by providing brief initial training, or shaping, on attending to the relevant dimensions of a problem.

STAGE 2. Transformation Processes

This stage represents a major departure from Guilford's model. While he considers transformations to be products of processes, we consider the processes of transforming to be fundamental and necessary as an initial stage of information processing. This stage includes all those processes which serve to encode appropriate information. In the trivial sense, S responds only to encoded information, never to actual stimuli, so transformations are fundamental. However, we use the term "transformation" in the nontrivial sense to refer to those initial active processes which convert cues into meaningful information. These rule-governed processes are, of course, subject to change or enrichment as, for example, when the child transforms stimuli into first letters, then words, then sentences. Of the potentially many ways in which stimuli can be transformed into meaningful information, there does seem to be one easily identifiable "dimension", which can be labelled as the analytic-synthetic dimension. Appearing as two separate cognitive factors in Bloom's taxonomy, these labels refer to those cognitive operations which serve either to break down stimuli into individually meaningful elements or to impose initial overall meaning upon discrete elements.

STAGE 3. Generation Processes

In this stage are included all the processes or operations which serve to generate solutions by systematically going beyond the already transformed information. Appropriate processes would include all logical manipulations, the detection of relationships, and the identification of rules or patterns of sequential stimuli. Bloom's extrapolation factor is clearly related here, and Guilford identifies two separate categories of productive operations, i.e., convergent and divergent operations. While we readily accept these two active processes, we feel that they constitute a single "dimension" rather than separate categories of information production or generation. Convergent generation is required when all information elements point to a single solution or response. Most tests, because they call for a specific solution, assess S's ability to manipulate encoded information in order to achieve an implied solution. "Logical thinking" is a general term which describes these cognitive processes or convergent generation. Divergent generation, conversely, refers to the more "creative" processes by which one achieves new, unusual, or many different solutions from the same information.

STAGE 4. Evaluation Processes

This stage contains all processes which serve to determine whether or not solution has been achieved. Interestingly, an argument may be made that only the single evaluative process of comparing exists, and that one is always comparing two units of information against each other or one unit of information against some internal or external criterion. In any event, the stage functions as the decision point. As Figure 4 indicates, if a negative evaluation occurs, there is feedback to each prior stage and the entire information-processing sequence may recycle with different rules involved at each stage.

Some general comments about the model are in order. Clearly, memory is a cognitive process and, as such, must be involved in processing information. The model explicitly admits this—in fact emphasizes the point—by showing that memory is involved at all stages. Stored in memory are not only currently generated outputs but also the more permanent types of information and solution rules which may be utilized at each particular stage. The circles in the memory section represent these sets of stored rule-governed processes. Moreover, these circles are shown to be connected to the output-of-the-evaluation stage in order to provide a mechanism for enriching these "executive routines" by allowing storage of all successfully used rules or processes.

The distinction between transformation and generation processes is critical. The utility of this distinction is best indicated in the following problem. This sequence

OTTFFSSEN_

is to be completed by filling in the last letter. Before reading further, the reader is urged to try to solve the problem and, in so doing, introspectively analyze the stages and processes involved in his solution.

The instructions are simple and this problem, as with all sequence-completion tasks, ostensibly emphasizes convergent generation. That is, the solution is implied in the relationships among all of the elements of information in the sequence. One must merely extend the pattern to include the next [missing] element. The critical stage in this particular problem, however, is not generation but transformation, for the problem becomes embarrassingly easy once the stimuli are "read correctly" or, in terms of the model, once the stimuli are transformed into appropriately meaningful information. This problem is in fact appropriate for an elementary arithmetic class, but it would be preceded by the following training. The first sequence would appear as

ONE TWO THREE FOUR FIVE SIX ___

and all children, reading the stimuli as the first six numbers, would easily extend the sequence with SEVEN in the blank space. Next, one might give the following sequence

ONE TWO THR FOU FIV SIX SEV __

and the stimuli would be easily recognized as the first three letters of the seven numbers. Hence, extending the pattern rule, most children would correctly write EIG. Then for the following sequence

ON TW TH FO FI SI SE EI __

the children would be set to transform the stimuli as the first two letters of the first eight numbers, and they could easily generate NI to complete the sequence. Finally, when faced with

OTTFFSSEN_

they would transform the stimuli, not just as familiar alphabetical characters but as the initial letters of the first nine numbers and the pattern would be extended easily with T.

The point of this example is that so long as the stimuli are transformed, or encoded, as simply letters, there can be no logical pattern generated which could then be extended to supply the missing letter. However, as soon as the stimuli are properly encoded as the initial letters of the first nine numbers, the pattern is obvious and the missing item is supplied easily.

Without the benefit of the preliminary training sequences, the final problem is, admittedly, unfair in the sense that it is highly unlikely that one would transform the stimuli appropriately. But the writer feels that this may be precisely the fault of many classroom assignments, i.e., the student is required to generate solutions without properly reading the problem or transforming the information. To solve certain algebraic problems, for example, one must first "read" a quantity in terms of its factors. Similarly in trigonometry the major difficulty often lies in first recognizing the identity substitution for an expression. In summary, students may all generate information equally well but they may differ considerably with respect to their ability to transform information, especially in the absence of a program which explicitly trains this initial stage of information processing.

Further evidence for the need to distinguish between information-transformation and information-generation processes can be found by examining established tests of cognitive abilities. Taken from the Kit battery, the tests examined here are selected to reveal the differential emphasis on the transformation-versus-generation stage and, furthermore, to illustrate the differential "loading" of each test on the synthetic-analytic dimension and the convergent-divergent dimension within, respectively, the transformation and generation stages.

The familiar Gestalt Completion Test (Cs-1) is one which requires only appropriate transformation for its solution. The S, shown incomplete pictures, must, according to this analysis, transform synthetically by employing rules for "filling in" lines and spaces. In fact, evaluation is immediate, or insightful, as soon as appropriate information is encoded. No additional generation is required except for transferring the encoded information directly to the evaluation stage.

The Free Associations Test (Fc-1), on the other hand, requires little transformation but much information generation. In this test a single word is given and S is required to list as many associations as possible. The word must be transformed as a meaningful word, of course, but beyond that the primary task is divergent generation, i.e., the generation of different responses evaluated against the criteria for reasonable association.

Most tests, however, involve both transformation and generation processes. For example, the Object Synthesis Task (Re-2) requires that two objects, such as "a nail and a shoe" be combined in some way to form a third object. In terms of the present model, one must first transform analytically, i.e., encode the many abstract characteristics of each item, then generate synthetically, i.e., combine selected characteristics to form a functionally meaningful new object (such as a spear, for the example above).

Finally, a simple identity matching test (Identical Pictures Test—P-3) offers an interesting analysis. The S is presented one sample stimulus and a number of matching stimuli, only one of which exactly matches the sample. In terms of our analysis, the transformation is neither analytic nor synthetic but neutral in the sense of merely encoding the stimuli as they exist. Similarly, no new information must be processed either synthetically or divergently, thus generation is also neutral. Evaluation, then, consists of merely comparing the stimuli against the sample (or stored memory of it) and finding the identical match. The fact that this task so clearly loads on a neutral, or null, point in both stages suggests that synthetic-analytic processes are best described along a dimension having a meaningful null, or zero, point and that convergent-divergent processes lie on a similar dimension.

Moreover, it should be readily apparent that this task could be made more difficult by changing it to a delayed matching-to-sample task in which the sample is not present at the time of matching. In such a task, memory is obviously emphasized, since the various stimuli are compared to a retrieved memory of the sample. However, the same transformation and generation processes are involved despite the addition of the high memory load. Thus, in the general model, memory is assumed to be involved—in either short- or long-term fashion—in all stages and does not itself represent a stage which is independent of all others. Stated differently, a task cannot, in our opinion, be adequately described solely in terms of its memory requirements and without regard to the transformation and generation processes involved.

By way of a general summary, the model tentatively proposed here emphasizes two stages of information processing. The initial transformation stage involves cognitive processes which encode appropriate and useful information. The second-generation stage involves cognitive processes which accept the encoded information and generate additional information which can be evaluated in terms of progress to a solution. Moreover, it is suggested that transformation processes can be usefully described in terms of a synthetic-analytic dimension; and that generation processes can be similarly described in terms of a convergent-divergent dimension.

Though this model does appear to be significantly different from Guilford's, it should be noted that his operation category of cognition does include processes which we call "transformations." Also, Guilford does present an operational model (p. 315) which he claims can be derived from his morphological SI model and which more closely resembles the model presented here.

With regard to general theoretical implications of the model, the first point to be made is that this type of model does not attempt to define the specific processes involved at each stage. The purpose of this model was to describe functional categories of cognitive processes in an effort to provide a tractable framework within which a systematic, intensive, further analysis could be made. Our model suggests four general categories: Attention Processes, Transformation processes, Generation processes, and Evaluation Processes. Within this framework the critical question of general psychological interest seems obvious: What are the specific ways in which developing humans attend, transform, generate, and evaluate? It was our intention to pursue this question and identify the specific cognitive abilities which can be employed at each stage.

These initial efforts forced us to favor a "dimensional approach" for identifying and organizing specific cognitive processes. This approach, used successfully by Osgood and his associates (Osgood, Suci, & Tannenbaum, 1957) in the analysis of "meaning", offers an efficient method for organizing a mere listing of ostensibly discrete processes. Already proposed are the synthetic-analytic dimension for describing transformation processes and the convergent-divergent dimension for describing generation processes. Other dimensions should become identified as one completes an intensive taxonomy of processes within each stage.

The theoretical significance of the distinction between transformation and generation processes apparently has indirect support from the developmental theory of Piaget. Although his theory is discouragingly elusive when applied to specific test situations, this writer feels that Piaget's processes of assimilation and accomodation correspond roughly to the processes of transformation and generation respectively.

Research on creativity training also tends to validate the two stages and the two dimensions proposed in the present model. The very successful research program conducted at the Wisconsin Research and Development Center by Professor Davis (see Davis, et al., 1968) has resulted in procedures which, in terms of the model, essentially train Ss first to transform analytically [encode specific characteristics], then generate divergently [suggest new uses on the basis of the specific characteristics]. In fact, one could describe the creative person as one whose dominant cognitive processes are of the analytic-divergent combination.

Finally, the model apparently has relevance for the study of "cognitive styles." The Hidden Figures Test, for example, reliably identifies two populations of people, i.e., "global versus analytical" types (see Davis, 1967). To solve this task S must simply detect a figure which is embedded, or hidden, within some larger, more complex, figure. In terms of the present model, the task differentiates those who transform synthetically (or those who cannot inhibit encoding of the entire figure) from those who transform analytically (or those who can encode the separate features and who, consequently, can detect, or match, the hidden figure). Because there are so many ways in which one may transform initially, it is not surprising that one develops a fairly fixed pattern of selecting these transformation rules. This pattern, then, is described as a "cognitive style" and assessed with tasks such as the Hidden Figures Test. According to the model, it should be assumed that these selection patterns occur at all four stages, and any complete cognitive style analysis, therefore, should include the identification of the dominant pattern at each level. The diagnostic value of such analyses among school-aged children seems too obvious to belabor here.

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IV
IMPLICATIONS FOR EDUCATION

As stated earlier, one reason for deriving a general model is that the model should provide a convenient system for describing an effective task analysis of any subject matter. A task analysis usually consists of breaking down a given pedagogical problem into sequentially requisite behaviors (or perhaps requisite cognitive processes which underlie the specific behaviors) so that a proposed training program is forced to consider explicitly all necessary intermediate behaviors. A general model can facilitate such a task analysis by guiding, or structuring, the type of questions asked. The present model, for example, would naturally structure the analysis in terms of the behaviors (or cognitive processes) involved in each of the four stages.

To illustrate the usefulness of such an approach, the writer's model will be used to describe an analysis of an elementary mathematics program. A mathematics program is used because the writer and Professor Thomas Romberg, a mathematics specialist in the Wisconsin Research and Development Center, initiated a research project designed to improve the teaching of elementary mathematics. These two principal investigators had agreed from the outset that the most fruitful approach involved first the identification of mathematical objectives then the identification of behaviors and/or cognitive processes which presumably mediate the acquisition of each mathematical objective. Although the writer was still struggling with the development of a tractable general model, the analytical approach was similar in the math project; hence, our thinking on that project can now easily be couched in terms of the model reported here.

The mathematics project, reported in detail elsewhere (Romberg, Fletcher, & Scott, 1968), began with a survey of general mathematics objectives and the decision that the first major goal or objective was mastery of addition and subtraction problems such as 2 + 3 = 5. The first step toward an analysis involved rewriting the problem as 5 = 3 + 2 and then, in its most general form, as A = B + X. Stated in this form, the problem conceptually becomes one of "comparing and equalizing", i.e., one must compare two quantities A and B and make them equal by adding to or taking away from. Stated more elaborately in terms of the 4-stage model, S must (1) attend to a specific attribute, e.g., numerousness; (2) transform, or encode, the specific values of A and B; (3) generate a method for eliminating the difference; and (4) evaluate the result by comparing A to B + X.

Accepting what was basically this analysis of the problem, our strategy was not to involve "numerousness" from the outset but, rather, to train Ss on the necessary operations [or processes] first by involving a stimulus attribute which was easily and immediately encodable, i.e., length. We, therefore, first trained Ss to attend to various attributes (shape, color, etc.) and then to attend to the critical attribute of length. Using calibrated rods, we then trained Ss to "compare and equalize" lengths, i.e., encode the [obvious] differences in length, reduce the difference by adding other lengths to one, and evaluate [compare] the results. All children could perform the correct operations with lengths; hence, in terms of the model appropriate cognitive processes and behaviors were established at each stage well before the more difficult attribute of numerousness was introduced. The "problem", therefore, consisted merely of training Ss to perform the identical operations with the new attribute of numerousness. This was achieved by a training program which gradually but systematically trained Ss to use first physical representations for units of length, then symbolic representations for units of lengths, [hence numbers], at which point the children were solving arithmetic problems in the form 5 = 3 ± X.

The programming details are irrelevant to the purposes of this paper. Suffice it to say that the program was reassuringly successful. The terminal performance of the children trained with our program was equal to that of another class of significantly higher initial abilities and which, trained with traditional procedures, spent much more time learning to solve the same problems. Moreover, the teacher reported that our program was inherently more interesting, motivating, and "understandable."

The point illustrated here is that although arithmetic objectives were first identified, the analysis was made in terms of general operations, or cognitive processes, and the training program explicitly emphasized first these general operations with non-arithmetic materials. Within each stage, the operations identified were patently simple, and all children were demonstrably capable of logically solving this class of problem from the very beginning. It was only necessary, then, to structure their experience so that new stimuli [ultimately, arithemtic stimuli] were gradually assimilated so that the same general operations could then be performed with new but equally meaningful arithmetic stimuli.

This general approach—analyzing in terms of underlying cognitive operations or processes —should be applicable to any subject matter. An analysis of elementary science concepts was made by a group convened under the auspices of the American Association for the Advancement of Science (1963). Though the analysis was more general than the type suggested in this paper, the group's organized outline of concepts seems to have been successful and it is being adopted widely throughout the country.

It would appear that reading would be particularly susceptible to this type of analysis. As the child progresses from reading letters, to words, to phrases, he is essentially transforming, or encoding, according to more complex rules. Moreover, in order to pronounce and read new words, he must rely upon derived rules for generating this new information. Hence, an operational analysis of reading could reveal some fundamental cognitive processes involved in both the transformation and generation stage.

Perhaps the most significant benefit derived from using this 4-stage model (or any similar model) is that, by imposing a common structure upon analyses within various subject matters, the model provides a convenient vehicle for organizing the results of independent efforts. For example, the identification of transformation processes, whether obtained from analyses of arithmetic, reading, or science, could be integrated for a more complete description of the dimensions of available transformation processes. It is precisely this kind of integration which is needed to improve this model or provide the basis for constructing an entirely different model. Moreover, as the model improves in completeness it obviously becomes more powerfully relevant to subsequent task analyses of any pedagogical problem.

V
CONCLUDING COMMENTS

This has been a report of unfinished experiments and nascent theoretical ideas. The primary purpose of the report is to leave behind some viable theoretical thoughts because the writer is convinced that more than anything else education desperately needs a useful general model which describes the cognitive abilities of children.

But whose responsibility is it to generate such a theory? Clearly not the experimental psychologist, for psychology has long ago opted to ape the other "hard" sciences by ignoring real-life learning situations and creating, instead, well-controlled but artificial laboratory situations in which to study and develop "miniature models." And the professional educators, yielding to the pressures of an understandably impatient nation, have had to implement changes in curriculum and texts in the often dim light of their own limited personal experience. What was lacking, clearly, was a sound technology of education; that is, an organization for incorporating existing knowledge and translating that knowledge into effective pedagogical methods and materials by slow, but systematic, research and development. Fortunately, a viable organization did develop recently to fill the obvious void: This organization, educational psychology, contains members who, individually, cross many academic disciplines. One may find within a single person enough knowledge of psychology and sufficient subject matter expertise to produce effective new educational materials. This type is rare, however, and must be the exception. In the writer's opinion, the most efficient technology includes "teams" of subject matter specialists and psychologists. Both may be defined operationally then as education psychologists. The unique result of such a team is their eventual recognition of the need for a common system or theory. But regardless of how this organization is composed, it is the educational psychologist who must assume the responsibility for generating the general theory or model which can integrate the miniature theories of psychology and which can apply to actual pedagogical problems.

But what type of model should be adopted? Certainly chemistry has profited immensely from the morphological Periodic Table developed by Mendeleef over 100 years ago. Any such morphological arrangement, i.e., a logical matrix of elements, does provide an aesthetically pleasing integration which reveals orderliness and relationships and which immediately discloses missing components. Guilford's SI represents such a morphological model and must be considered an enormous integrative contribution to educational psychology. The writer, however, obviously prefers an operational model which immediately emphasizes the active information-processing and solution-generating behavior which is characteristic of the learner. The most complete model will probably be a composite type in which operational stages are first defined and then a morphological table is constructed to describe the specific cognitive process within each stage.

The question of what model is best will, hopefully, be answered empirically. The model which serves best will emerge and survive. It is only necessary that educational psychologists with various interests and biases contribute to the construction of these general models. The writer intends to continue development of the model tentatively suggested here and he invites any comments on this or similar efforts made by others.

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