DOCUMENT RESUME

ED 061 102 SE 013 581

AUTHOR Fazio, Frank; Moser, Gene W.

TITLE Information Processing at the Memoryful and Memoryless Channel Levels in Problem-Solving and Recall Tasks.

PUB DATE Apr 72

NOTE 41p.; Presented at the National Association for Research in Science Teaching, Chicago, Illinois, April 1972

EDRS PRICE MF-$0.65 HC-$3.29

DESCRIPTORS Behavioral Science Research; *Cognitive Processes; *Information Theory; *Memory; Models; *Problem Solving; Psychology; *Recall (Psychological)

IDENTIFIERS NARST

ABSTRACT

A probabilistic model (see SE 013 578) describing information processing during the cognitive tasks of recall and problem solving was tested, refined, and developed by testing graduate students on a number of tasks which combined oral, written, and overt "input" and "output" modes in several ways. In a verbal chain one subject repeated the substance of a communication to a second person, who in turn relayed the information. Each subject then wrote a statement of what was heard. Other tasks included verbal problem solving and immediate and delayed recall. Between one and one-and-one-half bits of long term memory information were processed in problem solving and recall tasks. Some subjects restructured the terms of a communication during recall and differed in problem solving strategies. There were interactions between information input and information retrieved from long-term memory. Subjects could tolerate 47.6 percent increase of information input before "noise" interfered with problem solving. In recall tasks there was a 59.7 percent decrease of information input. An individual's cognitive processing style can be identified from parameters of the model. (A glossary of terms, definitions of model parameters, and 14 data tables are appended.) (Author/AL)

ERIC

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION
THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL OFFICE OF EDUCATION POSITION OR POLICY

ED 061102

INFORMATION PROCESSING AT THE MEMORYFUL AND MEMORYLESS CHANNEL LEVELS IN PROBLEM-SOLVING AND RECALL TASKS

NATIONAL ASSOCIATION FOR RESEARCH IN SCIENCE TEACHING

April 4, 1972
Chicago, Illinois

Frank Fazio
Gene W. Moser

Science Education
2609 Cathedral of Learning
University of Pittsburgh
Pittsburgh, Pennsylvania 15213

TABLE OF CONTENTS

Appendices

INTRODUCTION

Much of the activity that goes on in the classrooms in our schools can probably be categorized as involving either of two general types of cognitive processes. These are recall and problem solving. Botwinick[1] identifies recall as one of the three stages of memory. These stages are (a) registration or impression (b) retention, the lasting effect of registration and (c) recall. Recall is seen as a retrieval process and may be thought of as a searching and scanning mechanism which selects among many possibilities. Good[5] defines problem solving as a process of discovering or educing new relationships among things observed or sensed, the solution of which requires reflective thinking. Many educators would probably agree that problem solving and recall are different and that problem solving is of a higher order of cognitive process.

Since much of school learning involves the use of these psychological processes by students in handling recall tasks and problem solving tasks, it becomes a worthy area of research.

It is the object of this investigation to test a model which may qualitatively and quantitatively describe the information processed in these cognitive tasks of recall and problem solving.

The model has been developed in part by Moser[7] and is based upon the mathematical theory of the engineering aspects of communication.[11] Felen[3] recently applied the Moser Model in the analysis of information processing by students working on an overt problem solving activity, that of wiring an electric circuit. Moser[8] very recently has refined the model to where it can now be used to describe information processing of the cognitive tasks of recall, recognition, and problem solving, using various modalities of output known as verbal, written, and overt.

This particular study will test the Moser Model with regard to recall and problem solving tasks using several combinations of modalities of input and output.

STATEMENT OF THE PROBLEM

This study is exploratory and is designed to test various constructs of the Moser Information Theoretic Memory Model as a means of assessing information processing by humans in recall and problem solving cognitive tasks.

More specifically the investigation attempted to answer the following questions: What specific information values can be used to identify problem solving and recall tasks at the memoryful level (original)? What information values at the mathematically derived memoryless level (independent) can be used to identify these tasks? Can the model be used to qualitatively and quantitatively describe the time-decay of knowledge in a chain flow of information experiment? Are information values significantly related to an external measurement of intelligence?

PROCEDURE

The subjects for this study were graduate students enrolled in two graduate science education courses at the University of Pittsburgh during the 1971-72 academic year. Thirteen students were in one group, while eighteen students were in the other. Students volunteered to participate in the various learning experiments.

Thirteen graduate students in one course took the Hunt Test of Conceptual Level.[6] This test consisted of six questions to which the students were asked to respond in at least five or six sentences per each question. This activity was defined as a problem solving task. These same thirteen students were involved later in a chain flow experiment which was designed as a recall task. This involved a six minute monologue heard by three students. Two of the students immediately went to separate rooms to verbalize what they heard to other human receivers, who in turn generated that content to another human. Chains of four to six human receiver-transmitters were conducted in this manner. One of the initial receivers was delayed thirty minutes before starting a chain flow of information.

The second group consisting of eighteen students participated in several tasks which involved various modalities of stimulus-input and response-output. These tasks are described in the following paragraphs.

Fifteen graduate science education (elementary and secondary) students participated in this task. They were selected on the basis of previous findings of their having processed information in other experiments. Seven of the students listened to a specially designed verbal statement. This statement was on an audio-tape and had been used in a similar experiment four months previously. Two of the source receivers(subjects) were then selected to initiate a recall chain. A chain is the sequential "passing" of information from one human to another. When the chain was terminated, each of the fifteen subjects was asked to write a statement of what he had heard. They were given eighteen minutes to complete this recall task. Each statement was term-analyzed and placed in a matrix. Then information theoretic values were calculated for each subject's output in the chain recall and delayed recall tasks. It should be noted that the delay in recall involved thirty minutes for five subjects, twenty-five minutes for two subjects, and a range of twenty minutes to zero minutes for each of two remaining students. These two tasks will be subsequently referred to as "Chain Verbal" and "Delayed Recall."

Each of eighteen graduate science education students(elementary and secondary) was asked to solve an abstract problem which was on a type-written page. The problem involved an incestuous relationship between nine people who were identified with Greek-letter names. The subjects were to take the role of a court judge deciding on divorce proceedings and custody assignments. The problem statement was two hundred twenty-four words in length. The term location and wording sequences of the statements were specially constructed to establish an abstract type of problem. The criterion was a maximized error-correction level. The subjects each spent five minutes verbally "solving" the problem. The audio-tapes were term-analyzed and compared to the terms located in the source, which consisted of eighty-seven terms with a variety of twenty-six. Each subject's output was placed in a matrix and treated for information theoretic measures. This task will be subsequently referred to as "Gamma".

A six hundred word passage was read to a group of fifteen graduate science education students(elementary and secondary science). They then immediately spent eight minutes writing what they had heard (based on a time study ratio of writing and speaking rates for hearing a five minute passage).[8] The source of the content was abstracted from an article by Robert L. Sinsheimer ("The Brain of Pooh: An Essay on the Limits of the Mind," American Scientist, Vol. 59, No.1, pp.20-28). The written statements were term-analyzed. Each subject's tally of terms (sequential) was placed in a matrix and treated for information theoretic values. This task will be referred to as "Brain".

Eighteen graduate science education students (elementary and secondary science) were asked to respond to the question, "What is Science Learning?" This was designed as a free recall task.[9] The subjects were given fifteen minutes to write their own composition. Each composition was term-analyzed and the results were placed in a matrix for determining information theoretic values. This task will subsequently be referred to as "Science Learning".

Seventeen gradtuate science education students (elementary and secondary science) participated in the experiment. They were shown an overhead projection of fourteen colored geometric objects. These were of four colors and included squares, circles, and triangles (equal and right-angled). The desired state of affairs was to record objects scored on the basis of match and non-match criteria. These two groups of entries were placed in matrices and treated for information theoretic measures. Then each subject's total entries (match plus non-match) were again placed in matrices for the treatment by information theoretic procedures. This task will be referred to as "Classification".

The following is a summary of the six previously described cognitive tasks with reference to the modalities of stimulus-response used in the particular task. The tasks are arranged in the order in which they were described. All tasks pertain to those students in Group II (See Table 1).

COGNITIVE TASKS

Stimulus	Response
1. Stimulus (oral) (Chain Expt) Each student listens to oral presentattion concerning steady state and information theory.	1. Response (oral) Student orally tells another what he has heard in chain experiment.
2. Stimulus (oral) (Delayed Chain Experiment) Each student is asked to write what he heard.	2. Response (written) Student writes what he heard in Chain experiment.
3. Stimulus (written) Student reads paragraph about Gamma-marriage-triangle and is asked to solve the problem.	3. Response (oral) Student verbally, five minutes, solves the problem out loud into a cassette recorder.
4. Stimulus (oral) Instructor reads aloud six minute description of function of brain.	4. Response (written) Students immediately write all they can remember from the oral presentation.
5. Stimulus (written) What is science learning?	5. Response (written) Students write paragraph for fifteen minutes.
6. Stimulus (visual-perception of objects on a screen) Student asked to classify these objects.	6. Response (written) Student classified objects on paper.

The verbal and written statements in all the tasks were coded. The Hunt-Conceptual Level Test was coded using the modified Parakh Interaction Analysis System.(10) The students' responses in all the other tasks were coded for the noun-terms used in the output (Appendix II). The sequence and frequency of noun-terms used in the responses were recorded and processed according to the Moser Model.

RATIONALE FOR DATA TREATMENT

The model makes certain assumptions concerning human behavioral processes. (A) Human behavior is a stochastic process. When a human decides on a "course of action" to follow, that course of action can be described probabilistically.

(B) The behavior of humans is from an ergodic source. An ergodic source is a rather stable and consistent one where the probabilistic laws remain constant during the entire "course of action." (C) Human behavior is Markovian. When man is involved in a behavioral sequence of events, what he is about to do is conditioned by what he has just done.

In order to obtain and determine probabilistic data to describe the behavioral actions of students, it was necessary to break the behavior into a sequence of discrete events. This was done by using a coding system on the oral and written responses. All the tasks except the Hunt Test were coded for the order-sequence and frequency of terms used. These codes were placed into an interaction matrix and information theoretic values were calculated according to the theorems and constructs described in Appendix I. The original entries are placed into the matrix and the calculations based on these are referred to as the memoryful conditions. The Moser Model uses Markovian matrix calculations to raise the power of the original matrix to a condition of steady state where independence occurs. The condition of steady state is called the memoryless condition.

The Moser Information Theoretic Memory Model is diagrammed on the next page in Figure 1.

The environment provides a stimulus (oral and or written) input (H_x) which is processed in the Short Term Memory. The Coding process in the Short Term Memory is a filtering process which removes some noise. The Comparator(12) shown in the model is the processor of the noise components H_xY and H_yX.

The Code goes to the Long Term Memory store for search and retrieval of information. Real information and useful information is made up of the components, Code and LTM (Code + LTM). The error correcting mechanism in this model is the Comparator(12) which corrects or makes adjustments for the noise

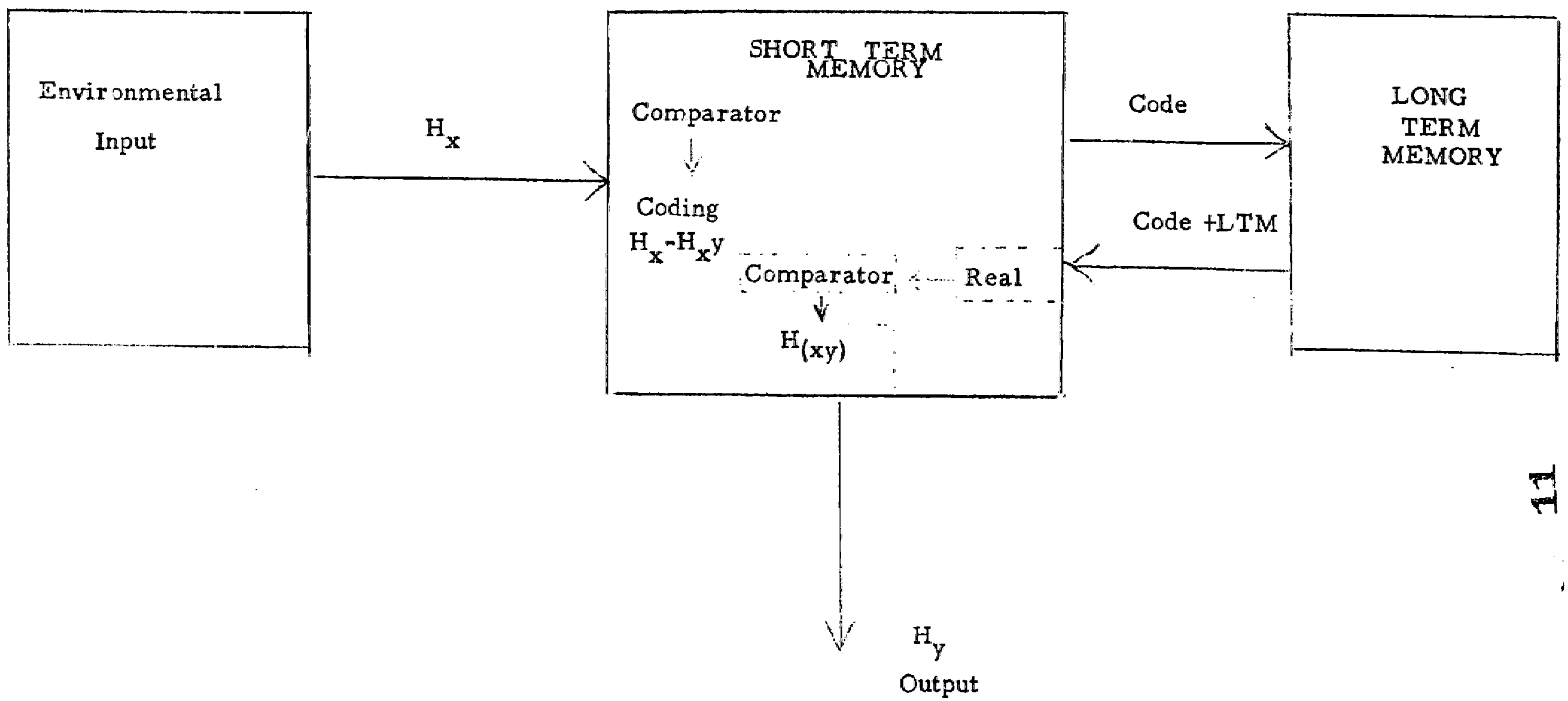

Figure 1. Moser Information Theoretic Memory Model

components H_xY and H_yX. The calculations of the information values in the Moser Model are explained in Appendix I and can be found in Shannon[11], Felen[3,4] and Moser.[7,8]

The Comparator mechanism in the Moser Model is similar to that mentioned by Sternberg.[11] The Comparator is part of the noise control or noise correction system. The Moser Model hypothesized that the noise components H_xY and H_yX are relevant variables that may help to identify cognitive tasks[8].

The following is a sequential outline of the data collection and processing procedures:

1. The observer codes the oral and or written responses according to the sequence and frequency of the coded terms.

2. The coded noun-terms (or Parakh codes) are placed into an Interaction matrix. (See Appendix II)

3. The probabilities based upon the frequencies of codes are calculated.

4. The conditional probabilities for the row entries are calculated.

5. The $p \log_2 p$ tables are used to calculate the average information values; H_x (input), H_xY (conditional probability), $H_{(max)}$, and Channel Capacity.

6. The other thirteen information values are calculated for both the original memoryful channel level and the steady state memoryless channel level.

FINDINGS

The analyses of the experiments will be described qualitatively and quantitatively with regard to the constructs proposed in the model. Generalizations are based upon some statistical decision rules, although some are pure inferences related to the model's hypothesized constructs.

The information values for all eight experiments performed with the two groups are summarized in Table 1.

Finding: 01

The amount of input information H_x processed by the subjects in the various experiments ranged from 2.242 bits in the Hunt Conceptual Level Test to 4.7511 bits in the "Science Learning" recall experiment.

The H_x Values are a function of the type of coding process used in the analysis. The Parakh Digram Code(10) was used on the Conceptual Level Test which explains why the input values are low for this task. The noun-term analysis was used on all the other experiments and the overall values for these ranged from 3.9016 to 4.7511 bits.

Finding: 02

The input information H_x is significantly correlated with the equivocation H_yX on the Conceptual Level Test at both the memoryful and memoryless channel levels. The r_{xy} values are 0.829 and 0.650 respectively. The recall chain experiment in Group I showed a significant correlation only at the memoryless level with a value of $r_{xy} = 0.957$. (See Table 2)

In the model, Equivocation H_yX is a component of noise in the channel which is processing information. Equivocation is often regarded as an error-correction factor. It seems from the data (Table 2) that H_yX is strongly related to the input H_x. For the problem solving task, the higher the value of the input component H_x, the higher the value of noise component H_yX becomes. However, this relationship is not true for the recall task in the original memoryful channel. Perhaps the nature of the information processing used in problem solving tasks requires more errors or more noise in the channel.

In the model the information value obtained from the Long Term Memory store is referred to as the LTM. The relatedness of the Equivocation H_yX value and the LTM value for the same subjects on the same cognitive task was determined. The relationship of the LTM at both channel levels for the same subjects processing both tasks was also determined.

Finding: 03

The H_yX and the LTM at the memoryful level showed a significantly negative correlation of $r_{xy} = -0.797$ for the Conceptual Level Test and a significant value of -0.6914 for the recall task for Group I. The Conceptual Level Test value for the LTM operating in the memoryful and the LTM in the memoryless channel were significantly correlated at $r_{xy} = 0.683$, but the recall task LTM values were not significantly correlated. (See Table 3)

Various other correlations were calculated to determine any relationships between the two tasks with reference to the information values H_yX, LTM, and Code. (See Table 4)

In the model, Code refers to that component of noise which is filtered out when the input H_x enters the Short Term Memory. It is defined as $H_x - H_xY$. The Code value in the memoryful channel level was not found to be significantly correlated between the two tasks in Group I.

Finding: 04

The LTM in the "Chain Recall" Task was significantly negatively correlated with the LTM value of the Conceptual Level Test at the memoryless level, with a value of $r_{xy} = -0.647$.

This finding may indicate that the tasks differ in the kind of Long Term Memory pathway which was used in processing information in the two tasks.

The second group of adult subjects participated in a series of six experiments. The tasks were a priori defined and designed to be three recall tasks and three problem-solving tasks. The three recall tasks in the data Tables 5-10 are referred to as (a) "Science Learning" (b) "brain" (c) "Delayed Recall"; the three problem-solving tasks are labeled (a) "Gamma (b) "Classification" (c) "Chain Verbal."

In order to demonstrate that the various cognitive tasks were of two general types, recall and problem-solving, it was necessary to show some degree of similarity between the same kinds of tasks and to show a significant difference between the different kinds of tasks. First, correlations were done to indicate the degree of independence of the data with regard to the model component H_yX/H_x. Establishing independence of the data, then a t-test was used to determine which of the task combinations were significantly different. (See Table 5)

"Chain Verbal" and "Delayed Recall" tasks were the only two tasks that were significantly related $r_{xy} = 0.609$. Since "Chain Verbal" and "Delay Recall" were significantly correlated, a t-test was not used.

Finding: 05

Correlations established a degree of independence of the data values with respect to the component H_yX/H_x, the amount of Error-correction per Input, in the various tasks except for "Chain Verbal" and "Delay Recall." Multiple t-tests show significant differences between the problem solving tasks and the recall tasks. No significance was found when comparing two recall tasks with each other nor when comparing two problem solving tasks with each other. When processing a problem solving task the amount of Error-correction per Input (H_yX/H_x) is significantly greater than when processing a recall task.

The model hypothesizes the Comparator mechanism.(8) This comparator is the error control system which operates in the memory. Processing of information in a problem solving task involves greater use of this control mechanism as evidenced from the data in Table 5. Inter-correlations between the combinations of six tasks in Group II, using the value H_yX/H_x in the memoryless channel, show only one significant value. This substantiates the model construct that Error-correction works in the memoryful condition but not effectively in the memoryless state.

Finding: 06

The LTM in the "Gamma" problem solving task and the LTM in the "Classification" task are significantly correlated $r_{xy} = 0.5243$ for the memoryful channel but not at the memoryless channel. The LTM values in other tasks were not significantly related.

With reference to Table 1 and attempting to find some identifying information values which might be used to characterize somewhat distinctly the two kinds of cognitive tasks, the following model components are noted: (A) the Conditional Relative Entropy ($H_x Y$ R.E.); (B) Percent Code Reduction; (C) Percent Real in the Shared Information; (D) Percent of total Noise in Shared and (E) the Error-correction per Input already mentioned in finding 05.

Finding: 07

The Conditional Relative Entropy ($H_x Y$ R.E.) values for the three recall tasks were 33.10%, 39.30%, and 38.75%, while the three problem solving tasks were all slightly higher at 40.02%, 44.60%, and 44.84%. Multiple t-tests (Table 12) show significant differences with respect to the recall tasks and problem solving tasks, except the value for "Classification" 40.02% is not significantly different from "Brain" value of 39.30%.

Table 8 shows that only the "Chain Verbal" task is correlated with the "Brain" recall task and with the "Science Learning" recall task. A multuple t-test was used to support the finding 07.

Table 7 shows that the Percentage of Code Reduction correlations between the six tasks were not significantly related except "Chain Verbal" with the "Delay Recall" task.

Finding: 08

The Percentage Code Reduction values for the three recall tasks were 69.80%, 72.11%, and 75.71% compared with the lower values for three problem solving tasks, 58.42%, 59.15%, and 59.27%. Multiple t-tests show that the tasks are significantly different from each other when problem solving is compared with a recall task. (See Table 12)

The Real information or Useful is a component of the Shared information $H_{(x,y)}$. The trend of this percentage may be able to be used to identify these two cognitive tasks.

Finding: 09

The percentage of the Real information of the Shared information was higher for the three recall tasks as compared to lower values for the three problem solving tasks. The values were 55.22%, 57.74%, 60.66% and 43.59%, 43.72%, and 45.27% respectively. Multiple t-tests supported the conclusion that significance occurs when comparing two different cognitive tasks. (See Table 11)

Noise in the information processing channel seems to be a useful identifying characteristic in distinguishing between these two kinds of tasks. The model hypothesizes that problem solving processing activity involves a greater searching for and comparing of information in the memory channel; as a result the total noise input in the problem solving processing should be higher.[8]

Finding: 10

The total amount of Noise in the memoryful channel - H_xY and H_yX - is higher for the problem solving tasks than for the recall tasks. The percentage noise of the Shared is higher in the problem solving tasks. The values are 39.34%, 42.26%, and 44.78% for the recall tasks and 56.28%, 56.41% and 54.73% for the problem solving tasks. Multiple t-tests strongly indicate that problem solving and recall tasks are significantly different with respect to Percentage of Noise in Shared.

Table 10 shows correlated comparisons between the six tasks with respect to input Relative Entropy (H_xR.E.). Only two significant correlations were found. The range of values for these Relative Entropies was 85.14% to 98.19%, with the highest value being in the task involving classification and sorting. The values for input Relative Entropies do not seem consistent and stable enough to reliably characterize cognitive tasks.

The strength of dependence is a numerical measure of the quality of the dependence between two subsequent events in a Markovian Chain. Comparisons were made of the strength of dependence measures calculated for the M^{16} state. The original matrix is multiplied by itself four times, M^1, M^2, M^4, M^{16}. Only three correlations out of fifteen were significantly related. The "Brain" recall task was correlated with two other tasks, a problem solving task and a recall task. Strength of dependence of "Science Learning" task was significantly correlated with the "Gamma" problem solving task. The strength of dependence measures vary considerably over all tasks and is not useful as a differentiating criterion for task identification. (See Table 9)

Strength of dependence values for students involved in the decay chain experiments varied considerably throughout the chain and no appreciable trend was noted. The variety of the original source terms used by the subjects in the verbal decay chain dropped considerably. The source had a variety of thirty terms, with the first subjects in the chain dropping to six and eight terms and the subjects at the end of the chain using only two or three terms. Most subjects in the chain experiment re-structured what they thought they had heard and used many new terms in their outputs. As a result of this new structuring, the strength of dependence used in the outputs was not affected by the decay of the original source terms.

Since two separate groups were used in the study, a t-test for differences between means was performed using the means for selected information values.[13] The Percent Code value and the Error- correction per Input were used as comparison criteria. (See Table 13)

The Percent Codes for Group I "Chain Verbal" and Group II "Gamma" were significantly different from each other. "Gamma" is a problem solving task; therefore, it can be concluded that Group I "Chain Verbal" is a recall task situation. This is further substantiated by comparing Group II "Delay Recall" written task with the Group I "Chain Verbal." No significant difference between the tasks is an indication that these two tasks are similar, supporting the conclusion that the Group I "Chain Verbal" task is a recall task.

The Group II "Science Learning" Percent Code and the "Brain" Percent Code are not significantly different from the Group I "Chain Verbal." Both the "Science Learning" and the "Brain" are recall tasks; therefore, it may be inferred that Group I "Chain Verbal" is being processed as a recall task, with reference to the model component Percent Code.

The Group I "Chain Verbal" Error-correction per Input value H_yX/H_x was compared with the "Gamma" value and was found to be significantly different. This is an indication of the model's hypothesized Error-correction value again being higher for the problem solving task than for the recall task. This lends more support to characterizing the Group I "Chain Verbal" as a recall task.

The Hunt Conceptual Level task was found to be significantly different when compared with other problem solving tasks in Group II. Perhaps the Hunt Test, being a written form of problem solving, involved an even greater amount of Error-correction per Input. The mean value for the Hunt Test was 47.1%, the highest of all tasks.

The Group I "Chain Verbal" task was not significantly different from the Group II "Chain Verbal" task when the H_yX/H_x values were compared. It may be that the similarity here is due to the verbal output modality. Both groups were verbally outputing information, so Error-correction is more closely related to the modality of output, while the information Percent Code is not.

Since the model attempts to explain and describe cognitive processes used in various cognitive tasks, and since intelligence is in part an indication of an individual's cognitive abilities, it is logical to look for relationships between the model's information values and an external measure of intelligence. The Miller Analogies Test[2] is a highly reliable measurement used for graduate students and serves as a useful general measure of intelligence. The M.A.T. scores for students in this study were compared with selected information values. In Table 14 the correlations between the M.A.T. scores and ten different information values are noted.

Finding: 11

The Miller Analogies Test Score was found to be significantly correlated with eight out of ten information values. The average recall values were found to be significantly correlated in eight out of ten values with three out of the eight being negatively correlated. The negative correlations were for Conditional (H_xY) Information, the Conditional Relative Entropy and the Error-correction per Input values.

ERIC

The values in Table 14 also indicate that "Science Learning" task had eight out of ten significant correlations with the M.A.T. scores while another recall task, "Delay Recall," had four significant correlations and the "Brain" recall task had no significant correlations. The problem solving averages were not significantly correlated, although the "Chain Verbal" task had seven significant correlations and the "Gamma" task had one.

These reported values (Table 14) were for the measures found in the memoryful condition of the memory. The memoryless condition measures are currently under study. To date, the Real measure has been found to be significantly correlated with the M.A.T. score in the "Science Learning" experiment($r_{xy} = -.6718$) and for the "average" recall task ($r_{xy} = -.5755$).

One may safely conclude that the M.A.T. is strongly correlated with recall type of tasks, especially those tasks like the "Science Learning" task which is a free recall type. The subjects who processed the "Science Learning" task expressed themselves in written form of output. It appears that M.A.T. is also related to certain problem solving tasks. Buros[2] found that the M.A.T. is a correlate of verbal ability and general intelligence. Perhaps one can conclude from the data in Table 14 that the dominant form of information processing used in the Miller Analogies Test is recall. From the Moser Memory Model then, it may be stated that M.A.T. is strongly related to the information values of the recall type of information processing. This process of searching is done in the Long Term Memory. The Moser Model's hypothesized L.T.M. construct was not significantly correlated with any of the M.A.T. values at the memoryful channel level[8]. Perhaps one can conclude that the LTM in the model is not really a measure of recall type of retrieval as related to the influence of the intellect but is probably more related to the interaction of memory model components. The "Classification values were not significantly correlated in any of the information values tested. According to the Moser Model, the classification-sorting type of task involves only the use of the short term memory. The stimulus objects used were projected on a screen and were visible during the entire time of the task. The subjects did not have to draw much from their own long term memory because the objects were constantly in front of them. Most of the information necessary in the processing of this task is strongly perceptual and was being held by the subjects in the short term memory.

CONCLUSION

The major educational value of this study is that it identified the ways in which individual humans processed information while conducting two kinds of cognitive tasks. The Moser Information Theoretic Memory Model has been tested and various components have been refined and developed as a result of this investigation. Actual classroom contextual learning activities can be characterized as either recall or problem solving tasks using several of the constructs in the model. The individual's cognitive information processing style can be partially identified from several of the information values used in the model.

The following information values can be used as identifying exemplars of the cognitive tasks, recall and problem solving; very recent studies indicate that these values listed below may vary according to the success subjects have in processing tasks.[4,8]

	Recall Task	Problem Solving Tasks
Information Term	Expected Range of Values	Expected Range of Values
Percent Code of Input	69 % -------- up	40 % -------- 60 %
Percent Real of Shared	55 % -------- up	0 % -------- 50 %
Percent Noise of Shared (H (x,y)	0 % -------- 45 %	50 % -------- up
Conditional Relative Entropy H_xY R.E.	0 % -------- 40 %	40 % -------- up
Error-correction per Input H_yX/H_x	0 % -------- 35 %	35 % --------up

The above range of values can be used to categorize tasks or they may be used to partially identify the mode or style used by an individual when involved in school tasks. This information theoretic model may be able to be used in

ERIC

conjunction with other diagnostic and evaluative techniques to help analyze instructional learning tasks.

The treatment in this paper revealed that certain information values in the model can be used as criterion measures for indicating an analysis of the Miller Analogies Test Score in terms of the model's references to the recall type of information processing. The M.A.T. score has been found to be significantly correlated with the following memoryful model components: a) Input Relative Entro H_X R.E.; b) Code; c) Percent Code Reduction; d) Error-correction/Input H_X; e) Conditional Relative Entropy H_XY R.E.; f) Percent Real of the Shared Information; g) Equivocation H_yX; h) Real memoryful and in the Real memoryless condition.

This investigation has demonstrated that the model is applicable in identifying two kinds of tasks involving various modalities of output, either written or verbal. The data collection, treatment, and the data processing techniques are quite feasible, and the results suggest a practical utility for applying the model in the study of school learning situations.

The study also recommends future research to develop a possible regression equation which may be used to predict Miller Analogies Test scores from the previously listed information values. Other external measures of mental abilitie and or mental processes should be studied within the framework of the model in order to establish some measures of validity.

ERIC

APPENDICES

ERIC Full Text Provided by ERIC

APPENDIX I

Programme for Information Theoretic Measures

1. Actual Information: H_x The entropy or the information of the source of messages $H_x = -\sum p \log_2 p$ (a negative sign in front makes the log values positive)

2. Bit : A contraction of words binary digit: a unit of the amount of information; the amount of uncertainty; one bit is the amount of information involved in the choice between two equally probable possibilities.

3. Channel Capacity: The capacity of a communication channel is equal to the number of bits per second which can be transmitted.

4. Code: The filtering out process; According to the Moser Model, the brain will process the incoming message and subtract the spurious noise.

5. Percent Code Reduction or Code Efficiency; A filtering out or chunking process, According to the Moser Model, the amount of H_x input in the code signal used for a match in the long term memory retrieval search.
$\%$ Code $=$ Code/H_x

6. Conditional Information or Dependent Information: The uncertainty in the received signals if the message sent be known.
H_xy the uncertainty of y given x
$H_xy = p_1 \sum p \log_2 p$

7. Equivocation: The uncertainty as to what symbols were transmitted when the received symbols are known: a form of noise (H_yx) ; Error-correction.

8. Information: A logarithmic measure of the improbability of a message in a given situation; the uncertainty or the entropy of a message.

9. Markoff Chain: A special stochastic process in which probabilities are dependent on previous events.

10. Maximum Information: (H_{max}) The variety of codes used in a matrix. Assume all items are equally probable. $H_{max} = \log_2 N$ N= variety

11. Memory: The storage center of the brain. According to the Moser Model, the Short Term Memeory and the Long Term Memory have different functions. STM processes incoming information with the use of the Comparator.

12. Noise: The portion of a transmission channel which is spurious, or in the Moser Model, it is the "non-useful" information. The two components of noise are H_xy and H_yx.

13. Percent Noise: The portion of the transmission channel which is spurious, errorful or which is not useful information.

$$H_xy + H_yx / H(x,y)$$

ERIC

APPENDIX I (Continued)

14. Noise in Input: The amount of spurious information in the input messages in a transmission channel or memory model. Moser Model refers to the error-correction per input as noise/H_x or $H_y x$ / H_x .

15. Real or Useful Information: The amount of information which is not spurious or the useful information flowing in the channel. According to the Moser Model it is the Code message signal plus that retrieved from the long term memory.

16. Percent Real: The portion of a transmission channel which is useful.

Real / $H_{(x,y)}$

17. Relative Entropy: The relative uncertainty or the amount of information in the choice of the sender.

$$R.E. = H_x / H_{max}$$

18. Conditional Relative Entropy $H_x y$ R.E. The amount of information in the second message with respect to the total possible information.

$$R.E. = H_x y / H_{max}$$

19. Shared Information: The amount of information shared by consecutive x and y messages in a transmission channel. $H_{(x,y)}$

20. Steady State: A condition in the Moser Model referred to as Memoryless; A condition in a finite Markoff Chain where the probability of a given state will be almost independent of the initial state.

21. Steady State Information: The information in an event when it has no dependence on the event preceding it.

22. Strength of Dependence: The numerical quality of dependence between X and Y events in a Markovian Chain. In the Moser Model it is the amount of code remaining when the matrix is multiplied by itself to M^{16} .

APPENDIX II

INTERACTION MATRIX SHOWING TERMS USED IN "SCIENCE LEARNING" TASK

Student J.W.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Freq	prob	plog$_2$p	adjusted Row Sum
1. I		3	1																	4	.0635	.2538	.0515
2. Think			2	1																3	.0476	.2103	.0437
3. Science Learning	2			2								1	1		1					7	.1111	.3520	.2485
4. Understanding					1			1		1		1	1	1						6	.0952	.3226	.2461
5. Student						1	1				1	1				4		1	1	10	.1587	.4218	.4002
6. School					1		2													3	.0476	.2073	.0437
7. Learning				2		1		1												4	.0635	.2538	.0953
8. Fact	1								1											2	.0318	.1589	.0318
9. Formula				1																1	.0159	.0862	-
10. Science					1															1	.0159	.0862	-
11. Understand					1												2			3	.0476	.2103	.0437
12. Thing			3		1							1								5	.0794	.2893	.1088
13. Teach						1	1													2	.0318	.1589	.0318
14. Life	1																			1	.0159	.0862	-
15. Inquiry					1															1	.0159	.0862	-
16. Learn												2						1		3	.0476	.2073	.0437
17. Aware																		2		2	.0318	.1589	0
18. Question					4															4	.0635	.2538	0
19. Experiment												1								1	.0159	.0869	-
																		Totals		63		H_x 3.8900	
																							$H_x y$ 1.3888

Cells Occupied 33
Variety 19
Channel Capacity 5.044
H_{max} 4.248

H_x R.E.= .9157

$H_x y$ R.E. = .3590

TABLE 1

SUMMARY OF INFORMATION VALUES FOR COGNITIVE TASKS
AT THE MEMORYFUL LEVEL (bits/coded symbols)

	Group II						Group I		
TASKS	Chain Verbal	Delay Chain Written	Brain Written	Science Learning Written	Gamma Verbal	Classification-sorting Written	Conceptual Level	Chain Verbal	Source
Hx (input) Relative Entropy	3.9139 86.48%	4.2468 90.61%	4.0069 85.14%	4.7511 90.79%	4.3140 89.29%	3.8306 98.19%	2.2739 85.94%	3.9016 93.56%	4.512 91.95%
HxY Relative Entropy	1.5940 44.60%	1.2824 38.75%	1.1173 39.30%	1.1540 33.10%	1.7621 44.84%	1.5926 40.02%	1.4737 35.56%	1.1243 39.51%	1.611 37.27%
Code % Code Input	2.3199 59.27%	2.9644 69.80%	2.8896 72.11%	3.5971 75.71%	2.5519 59.15%	2.2380 58.42%	.8002 35.19%	2.7773 71.2%	2.901 64.29%
Channel Capacity	5.6815	5.6183	5.1935	5.8901	6.1811	5.5496	4.1447	5.0784	72 6.170
Hy (output)	4.0875	4.3359	4.0762	4.7361	4.4190	3.9570	2.6710	3.9541	4.559
Real % Real of Shared	2.4935 45.27%	3.0535 55.22%	2.9589 57.74%	3.5821 60.66%	2.6569 43.72%	2.3644 43.59%	1.1973 52.7%	2.8298 56.3%	2.948 48.14%
HyX	1.4204	1.1933	1.0480	1.1690	1.6571	1.4662	1.0807	1.0718	1.564
H(x,y)	5.5079	5.5292	5.1242	5.9051	6.0761	5.4232	3.7477	5.0259	6.123
L.T.M.	.1736	.0891	.0693	.0150	.1050	.1264	.3971	.0325	.040
Noise (HxY+HyX) % Noise of Shared	3.0144 54.73%	2.4757 44.78%	2.1653 42.26%	2.3230 39.34%	3.4192 56.28%	3.0588 56.41%	2.6544	2.1961 43.70%	3.175
HyX/Hx	.3541	.2294	.2658	.2510	.3889	.3821	.4709	.2760	.3466

TABLE 2 PRODUCT MOMENT CORRELATION COEFFICIENTS AND REGRESSION ANALYSIS AT MEMORYFUL AND MEMORYLESS CHANNEL LEVELS

Group I

	Conceptual Level Test (Problem-solving Task)		Chain Experiment (Recall Task)	
	Memoryful	Memoryless	Memoryful	Memoryless
Hx (mean)	2.242	2.242	3.902	3.847
HyX (mean)	1.058	1.499	1.078	3.300
b_{yx}	0.810	3.194	0.116	1.256
b_{xy}	0.849	0.132	0.492	0.729
a_y	-0.829	-5.663	0.626	-1.534
a_x	1.385	2.044	3.371	1.441
r_{xy}	0.829*	0.650*	0.237	0.957*

* $r_{xy} \geqq 0.553$ significant at 5%

TABLE 3 PRODUCT MOMENT CORRELATION COEFFICIENTS AND REGRESSION ANALYSIS AT VARIOUS CHANNELS

Group I

Conceptual Level Test	r_{xy}	a_x	a_y	Chain Experiment	r_{xy}	a_x	a_y
H_yX-vs-LTM (Memoryful)	-0.797*	1.564	0.921	H_yX-vs-LTM (Memoryful)	-0.691*	1.180	0.861
LTM-vsLTM (Memoryful - Memoryless)	0.683*	0.137	0.212	LTM-vs-LTM (Memory - Memoryless)	0.253	1.167	0.560

* significant at 5%

TABLE 4 PRODUCT MOMENT CORRELATION COEFFICIENTS AND REGRESSION ANALYSIS BETWEEN THE COGNITIVE TASKS

Group I

Conceptual Level Test		Chain Experiment	r_{xy}	a_x	a_y
H_yX (memoryful)	vs	H_yX (memoryful)	-0.474	1.976	1.344
Hx (memoryless)	vs	H_yX (memoryless)	-0.463	4.969	2.133
LTM (memoryful)	vs	LTM (memoryful)	-0.308	0.418	0.480
LTM (memoryless)	vs	LTM (memoryless)	-0.647*	1.097	1.123
Code (memoryful)	vs	Code (memoryful)	0.080	2.396	0.756

* significant at 5%

TABLE 5 PRODUCT MOMENT COEFFICIENTS AND t-TESTS FOR SELECTED COMPARISONS OF ERROR-CORRECTION PER INPUT OF INFORMATION BETWEEN SIX COGNITIVE TASKS

Group II

Cognitive Tasks*	r_{xy}	t	
Science Learning vs Gamma	0.0823	-4.1662	**
Brain vs Gamma	-0.3845	-3.8956	**
Brain vs Classification	0.2142	-3.6804	**
Science Learning vs Classification	- 0.0335	4.1487	**
Gamma vs Classification	0.0350	0.1994	NS
Science Learning vs Brain	0.2914	0.9222	NS
Chain Verbal vs Delay Recall	0.6087#	---	

Significant at .05 level
** Significant at .01 level

* For a description of these cognitive tasks see pages 4-6 in the procedure section.

TABLE 6 PRODUCT MOMENT CORRELATIONS OF SELECTIVE COMPARISONS OF COGNITIVE TASKS AT THE MEMORYFUL AND MEMORYLESS CHANNEL LEVELS FOR THE LTM

Cognitive Tasks *	r_{xy}	
Science Learning - Gamma		
a) Memoryful	-0.433	
b) Memoryless	0.007	
Science Learning - Brain		
a) Memoryful	-0.0297	
b) Memoryless	0.224	
Brain - Gamma		
a) Memoryful	-0.056	
b) Memoryless	-0.326	
Gamma - Classification		
a) Memoryful	0.5243#	a_x=.0350 a_y=0.0730
b) Memoryless	0.1445	
Verbal Chain - Delay Recall		
a) Memoryful	-0.025	
b) Memoryless	0.128	
Brain - Classification		
a) Memoryful	-0.0143	
b) Memoryless	0.0985	

#Significant at the 5% level

* For a description of these cognitive tasks see pages 4-6 in the procedure.

TABLE 7 PRODUCT MOMENT CORRELATIONS FOR SIX COGNITIVE TASKS FOR THE PERCENTAGE OF CODE REDUCTION IN THE MEMORYFUL CHANNEL LEVEL

Tasks	1	2	3	4	5	6
1. Chain Verbal	-	.5641*	.2698	.6581*	.0413	.1344
2. Delay Recall	-	-	.0092	.2713	-.1466	.3097
3. Brain	-	-	-	.1191	.0532	-.2091
4. Science Learning	-	-	-	-	.1678	.0791
5. Gamma	-	-	-	-	-	.1273
6. Classification	-	-	-	-	-	-

TABLE 8 PRODUCT MOMENT CORRELATIONS FOR SIX COGNITIVE TASKS FOR THE CONDITIONAL RELATIVE ENTROPY ($H_{x/y}$ R.E.) AT THE MEMORYFUL CHANNEL LEVEL

Tasks	1	2	3	4	5	6
1. Chain Verbal	-	0.1803	0.5461*	0.5385*	-0.1139	0.1872
2. Delay Recall	-	-	-0.0544	0.0351	0.0209	-0.0339
3. Brain	-	-	-	0.0979	-0.0565	0.1177
4. Science Learning	-	-	-	-	-0.0058	0.2412
5. Gamma	-	-	-	-	-	0.1020
6. Classification	-	-	-	-	-	-

* Significant at the 5% level

TABLE 9 PRODUCT MOMENT CORRELATION FOR SIX COGNITIVE TASKS FOR THE STRENGTH OF DEPENDENCE IN GOING FROM THE MEMORYFUL TO THE MEMORYLESS CHANNEL LEVEL

Tasks	1	2	3	4	5	6
1. Chain Verbal	-	.2553	.6971*	-.4800	-.0118	.3297
2. Delay Recall	-	-	.8858*	.1640	.1758	.3905
3. Brain	-	-	-	-.0602	.3915	.0724
4. Science Learning	-	-	-	-	.9322*	-.1850
5. Gamma	-	-	-	-	-	-.0813
6. Classification	-	-	-	-	-	-

TABLE 10 PRODUCT MOMENT CORRELATIONS FOR SIX COGNITIVE TASKS FOR THE INPUT RELATIVE ENTROPY (H_x R.E.) AT THE MEMORYFUL CHANNEL LEVEL

Tasks	1	2	3	4	5	6
1. Chain Verbal	-	-.3712	.5675	.6638*	.0307	.2596
2. Delay Recall	-	-	-.1135	.0993	.4527	.0089
3. Brain	-	-	-	.0926	-.3366	-.1982
4. Science Learning	-	-	-	-	-.1356	.4384
5. Gamma	-	-	-	-	-	.1483
6. Classification	-	-	-	-	-	-

* Significant at .05 level

TABLE 11 PRODUCT MOMENT CORRELATIONS FOR SIX COGNITIVE TASKS FOR THE PERCENT REAL INFORMATION VALUE IN THE MEMORYFUL CHANNEL LEVEL

Tasks	1	2	3	4	5	6
1. Chain Verbal	-	.7074*	.1275	.2418	-.0534	.0293
2. Delay Recall	-	-	.1870	.2810	-.2014	-.0859
3. Brain	-	-	-	-.2458	-.3468	.4433
4. Science Learning	-	-	-	-	-.2379	.1599
5. Gamma	-	-	-	-	-	-.1799
6. Classification	-	-	-	-	-	-

TESTING DIFFERENCES OF MEANS OF THE PERCENT REAL INFORMATION VALUE BETWEEN COGNITIVE TASKS

Tasks	t-ratio	
1. Science Learning (Recall) vs Gamma (Problem Solving)	5.50113	**
2. Brain(Recall) vs Science Learning(Recall)	-1.89519	ns
3. Gamma (Problem Solving) vs Classification (Problem Solving)	.2710	ns
4. Chain Verbal (Problem Solving) vs Gamma (roblem Solving)	0.6929	ns
5. Brain (Recall) vs Gamma (Problem Solving)	3.91535	**
6. Delay Recall(Recall) vs Brain (Recall)	- 0.46072	ns
7. Science Learning(Recall) vs Classification (Problem Solving)	5.7110	**
8. Delay Recall (Recall) vs Gamma (Problem Solving)	3.0601	**

* Significant at .05 level
** Significant at .01 level

TABLE 12 TESTING DIFFERENCES OF MEANS BETWEEN TASKS IN GROUP II USING PERCENT CODE REDUCTION AND CONDITIONAL RELATIVE ENTROPY($H_x y$ R.E.)

Tasks (Percent Code Reduction)	t-ratio	
1. Gamma (Problem Solving Task) vs Science Learning(Recall Task)	-10.926	**
2. Gamma (Problem Solving) vs Brain (Recall Task)	- 2.966	*
3. Brain (Recall Task) vs Science Learning (Recall Task)	-1.8089	ns
4. Chain Verbal (Problem Solving Task) vs Gamma (Problem Solving)	0.2197	ns
5. Gamma (Problem Solving) vs Classification (Problem Solving)	- 0.3333	ns
6. Chain Verbal (Problem Solving) vs Brain (Recall Task)	- 2.008	#
7. Delay Recall (Recall Task) vs Science Learning (Recall)	-1.921	ns
8. Delay Recall (Recall) vs Brain (Recall Task)	-0.0416	ns

Tasks (Conditional $H_x y$ R.E.)	t-ratio	
1. Brain (Recall Task) vs Gamma (Problem Solving)	-1.635	ns
2. Verbal Chain (Problem Solving) vs Gamma (Problem Solving)	-0.0195	ns
3. Gamma (Problem Solving) vs Classification(Problem Solving)	0.742	ns
4. Brain (Recall Task) vs Science Learning (Recall Task)	2.10.	*
5. Gamma (Problem Solving) vs Science Learning (Recall)	4. 481	**
6. Verbal Chain (Problem Solving) vs Delay Recall	0.7922	ns
7. Science Learning vs Delay Recall	2.078	#
8. Brain (Recall Task) vs Delay Recall	0.1549	ns

** Significant at .01 level
* Significant at .05 level
# Significant at .07 level

TABLE 13 TESTING DIFFERENCES BETWEEN MEANS OF GROUP I AND GROUP II COGNITIVE TASKS USING SELECTED INFORMATION VALUES

	Tasks Comparing % Code Value	t ratio
1.	Group I Chain Verbal -vs- Group II Gamma	3.3457**
2.	Group I Chain Verbal -vs- Group II Chain Verbal	2.281 *
3.	Group I Chain Verbal -vs- Group II Delay Recall	0.1883 NS
4.	Group I Chain Verbal -vs- Group II Science Learning	-1.8118 NS
5.	Group I Chain Verbal -vs- Group II Brain	0.1393 NS
	Tasks Comparing Error-Correction/Input	
1.	Group I Chain Verbal -vs- Group II Gamma	-3.1107**
2.	Group I Conceptual-Level -vs- Group II Chain Verbal	2.856 **
3.	Group I Conceptual-Level -vs- Error-Correction/Input	2.8836**
4.	Group I Chain Verbal -vs- Group II Chain Verbal	-1.4663 NS

* Significant at .05 level
** Significant at .01 level

TABLE 14 PRODUCT MOMENT CORRELATIONS OF SELECTED STUDENT INFORMATION VALUES AND THE MILLER ANALOGY TEST SCORES

		r_{xy}
A. MAT -vs-	Input Relative Entropy H_x R.E.	
	Recall Tasks Average	0.6009 *
	a) Science Learning	0.7099 *
	b) Brain	-0.2153
	c) Delay Recall	0.4027
	Problem Solving Tasks Average	0.1006
	a) Gamma	0.0442
	b) Chain Verbal	0.2295
	c) Classification	-0.0604
B. MAT -vs-	Code	
	Recall Tasks Average	0.6514 *
	a) Science Learning	0.7825 *
	b) Brain	0.0406
	c) Delay Recall	0.4606
	Problem Solving Tasks Average	0.0417
	a) Gamma	-0.1434
	b) Chain Verbal	0.7007 *
	c) Classification	0.1432
C, MAT-vs-	Percent Code	
	Recall Tasks Average	0.8117 *
	a) Science Learning	0.7410 *
	b) Brain	-0.0340
	c) Delay Recall	0.5825 *
	Problem Solving Tasks Average	0.1192
	a) Gamma	-0.7996 *
	b) Chain Verbal	0.6225 *
	c) Classification	0.1442

* Significant at the .05 level

TABLE 14 (Continued)

	r_{xy}
D. MAT vs Error-Correction per Input $H_y x/H_x$	
Recall Tasks Average	-0.8264 *
a) Science Learning	-0.6779 *
b) Brain	-0.0668
c) Delay Recall	-0.7336 *
Problem Solving Tasks Average	0.0005
a) Gamma	0.1141
b) Chain Verbal	-0.7828 *
c) Classification	-0.0704
E. MAT vs Conditional Relative Entropy $H_x y$ R.E.	
Recall Tasks Average	-0.7266 *
a) Science Learning	-0.7668 *
b) Brain	0.1265
c) Delay Recall	-0.5361
Problem Solving Tasks Average	-0.1669
a) Gamma	0.0426
b) Chain Verbal	-0.7811 *
c) Classification	-0.1519
F. MAT vs Percent Real	
Recall Tasks Average	0.8428 *
a) Science Learning	0.7294 *
b) Brain	0.0756
c) Delay Recall	0.7378 *
Problem Solving Tasks Average	0.2606
a) Gamma	-0.07194
b) Chain Verbal	0.8001 *
c) Classification	0.3109
G. MAT vs L.T.M.	
Recall Tasks Average	0.0263
a) Science Learning	0.1984
b) Brain	0.1263
c) Delay Recall	-0.2165
Problem Solving Tasks Average	-0.1397
a) Gamma	-0.0778
b) Chain Verbal	0.0764
c) Classification	-0.1843

* Significant at .05 level

TABLE 14 (Continued)

H. MAT -vs- Percent L.T.M

Recall Tasks *Average*	-0.3459	
a) Science Learning	-0.4830	
b) Brain	0.2884	
c) Delay Recall	-0.1380	
Problem Solving Tasks *Average*	-0.2113	
a) Gamma	-0.0107	
b) Chain Verbal	-0.3036	
c) Classification	-0.2637	

I. MAT -vs- Equivocation H_yx

Recall Tasks *Average*	-0.8284	*
a) Science Learning	-0.6576	*
b) Brain	-0.0344	
c) Delay Recall	-0.8312	*
Problem Solving Tasks *Average*	-0.1150	
a) Gamma	0.0738	
b) Chain Verbal	-0.7349	*
c) Classification	-0.0769	

J. MAT -vs- Real Information

Recall Tasks *Average*	0.7328	*
a) Science Learning	0.7367	*
b) Brain	0.1133	
c) Delay Recall	0.5504	
Problem Solving Tasks *Average*	0.0063	
a) Gamma	-0.1149	
b) Chain Verbal	0.8474	*
c) Classification	0.0735	

ERIC

BIBLIOGRAPHY

1. Botwinick, Jack. Cognitive Processes in Maturity and Old Age, New York: Springer Publishing Company, Inc. 1967.

2. Buros, Oscar K. The Sixth Mental Measurement Yearbook, New Jersey: The Gryphon Press, 1965 (746 - 750).

3. Felen, Barbara K. "Information Theory Applied To The Analysis Of The Problem-Solving Using The Parallel Circuit Model," Paper presented to the Nationa Association for Research in Science Teaching, March, 1971.

4. Felen, Barbara K. and Gene W. Moser. "Information Processed by Negroid and Caucasian Children Engaged in Problem-Solving Tasks," Paper presented to National Association For Research in Science Teaching, April, 1972.

5. Good, Carter V. Dictionary of Education, New York: McGraw-Hill Book Company, 1959.

6. Hunt, D.E., Lapin, S., Liberman, B., McManus , J., Post, R., Sabalis, R., Sweet, S., and Victor, J.B. Manual for Coding Paragraph Completion Responses for Adolescents. Unpublished manuscripts, Syracuse University Youth Development Center, 1968.

7. Moser, Gene W. "An Information Theoretic Interpretation of Science Interactic Dialogues," Paper presented at the National Association for Research in Science Teaching, March, 1971.

8. Moser, Gene W. "An Information Theoretic Model for The Human Processing of Cognitive Tasks," Paper presented to the National Association for Research in Science Teaching, April, 1972.

9. Norman, Donald A. Memory and Attention An Introduction to Human Information Processing, New York: John Wiley & Sons, Inc. 1969, p 82-83.

10. Parakh, Jal S. "A Study of Teacher-Pupil Interaction in High School Biology Classes: Part 1 The Development of a Category System," Journal of Research in Science Teaching, 5, 284-292, 1967-68.

11. Shannon, Claude E. and Warren Weaver. The Mathematical Theory of Communicatic Urbana, Illinois: The University of Illinois Press, 1964.

12. Sternberg, Saul. "Memory-Scanning: Mental Processes Revealed by Reaction-Time Experiments," American Scientist, 57, 421-457, No 4, 1969.

13. Walker, Helen M., and Lev, Joseph. Statistical Inference, New York: Holt, Rinehart and Winston, 1953.