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AUTHOR	Moser, Gene W.
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ABSTRACT

An information-theory model of human memory was tested in thirteen experiments which involved children (six years and older) and graduate students. The subjects conducted science investigations in laboratory and non-laboratory settings, solved problems of electrical circuits, and participated in classroom science lessons. The tasks used involved problem solving, recognition, and immediate and delayed recall. The model gave meaningful descriptions of cognitive processing, allowed isolation of several memory processes, and provided evidence of learning information processing. The differences in the kind of information processed during various cognitive tasks were due to interactions; for example, between input information and long-term memory. Problem solving tasks involved controlling and balancing "noise" in the input and output information channels; recall processing differed from problem solving by an inverse management of noise control. The data represent the first significant demonstration of Shannon's 1948 theorem on error capacity of communication channels. The model, with universal applications for describing human behavior, may allow interpretation of how and when learning occurs. (A glossary of terms and data tables are appended. A simplified diagrammatic version of the model is included.) (Author/AL)

An Information Theoretic Model for the Human Processing of Cognitive Tasks

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Gene W. Moser
Science Education
C.L. 2610
University of Pittsburgh
Pittsburgh, Pa. 15213

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* Abstracted statements

Introduction

Claude Shannon (1) formulated the Mathematical Theory of Communication over twenty years ago. Since then its' name has been changed to Information Theory and has been applied to a number of other fields. The late H. Quastler (2) applied it to molecular organization and evolution. Several psychologists (3,4,5) then applied the theorems to the study of learning behavior. Some recent work (6,7) has been done on the information processed in learning experiences. G. A. Miller (8) used it to establish that humans, operating under certain conditions, can "remember" seven, plus or minus two, items placed in a series. Other researchers (9,10,11) have used the theorems in the study of language. Leeuwenberg (12) and Garner (13) have recently tried to interpret picture structure and richness with information theoretic measures. Eventually, some theoreticians (14,15,16,17) attempted to incorporate Information Theory into a memory model. Their attempts unfortunately, did not test the validity of the models with experiments on human behavior. Hsia (18) was the one researcher who attempted to explain visual and auditory inputs and mental processes by information measures. His attempt was confusing because he did not adequately define the information theoretic measures and explain how they functioned in cognitive processes.

There is still some hope that Information Theory is a body of knowledge which can describe cognition and can interpret how the human memory functions in processing tasks. The relationship of interpretative values for the use of Information Theory has been elusive. It is claimed that J. Piaget (19) believes Information Theory may provide a means for interpreting child development. Deutsch (20) recently reported that tonal sounds are logarithmically arranged in the human memory. Trehub (21) has found that visual representations are treated as a Fourier series in the brain. The information theoretic measures are based upon the numerical foundations of Fourier series and base two logarithms.

The author, being a cyberneticist, believes Information Theory has a logic system which, when interpreted in a particular manner, does serve as a means for explaining human memory and its functions. The task is one of interpreting theorems and of constructing theorems which enable an exhaustive correspondence of them with the "known" processes of the human memory. These processes are related to cognition and the behavior of man in an environment. The model of a memory needs to take into account how man moves "through" the environment, how the memory responds or reacts to perceptions, and how model components interact with each other in enabling an interpretation of those human behaviors. An information theoretic kind of model is more difficult to understand than qualitative models because all the information being processed in memory actions are numerically labelled. However, it is probably the appropriate model approach because behaviors seem to be discrete, are variety distinguishable, and involve numerical considerations.

This report should be regarded as an interim one because, as it will be seen by the reader, there are some refinements and additional definitions which need to be done.

The memory model described in this report is quite complicated. The verbal description is in a systems kind of presentation. This may seem confusing to the reader. However, it seems to be the best way for the description to be comprehended by the reader.

Purpose of the Problem

The problem was to determine the applicability of a memory model, based upon Information Theory, to the observed behaviors of humans engaged in processing cognitive tasks. The model was developed by studying the meanings of Information Theory principles and interpreting psychological studies of behavior which did or did not use information measures. The outcome was the deriving of new information measures and testing how they facilitated the interpreting of human behavior.

The memory model was completed in 1971. Twenty-two experiments have been used for criterion tests in the past year. Thirteen of the experiments are reported for illustrating the model, for relating its applicability to human processing of cognitive tasks. In each data treatment we have carried out tests of the similarities of data and the roles of those data in interpreting the behaviors of humans.

We have concluded that human behavior possesses observable patterns which are Markovian. The conclusion was reported in a paper at the 1971 NARST conference (22). Four sets of data have been computer-treated, tested and found to be Markovian since the presentation.

It has been an issue that behavior data are Markovian as a consequence of their having been coded. The observed behaviors are coded using a modified Parakh Category System (23), the Gallagher-Aschner System (24), or by a noun-pronoun term analysis system which was devised at the University of Pittsburgh. The codes are placed in a matrix which relates consecutive codes to each other. We have also studied behaviors which were not coded. These were experiments for studying how humans solve two different kinds of electric circuit problems. The electrical connection events were also placed in matrices. One of these studies was reported by B. Felen and G. Moser (25) at the 1971 NARST conference. The major finding was that both observation treatments of human actions obtained information values which were very similar. This finding has prompted a question of whether or not either the observational means were "reading" the behaviors of humans and whether or not such observed behaviors were in some way interpretable as being cognitive behaviors.

The second aspect of the problem was to test each of nine primary and nine secondary information theoretic measures for relatedness to each other and to external variables. The former was to determine how each measure interacts within the memory model. The second phase was to test how model components were related to cognitive and conceptual measurements of human learning behavior.

The primary rationale of Information Theory is the quantifying of the uncertainty of communication elements, or observed human actions or behaviors. The term uncertainty is taken literally and is regarded as information which measures the freedom of a human to process a task. Uncertainty does not quantify any one event or action but rather the "evenness" of the structure of a set of events or actions executed in a task. The reader is urged to keep this in mind when he reads the subsequent treatments and findings.

Procedure

Thirteen studies and experiments were used to test the model. The descriptions of these are in Appendix I. They involved children, beginning at six years, and adults from two universities. The experiments were designed to vary modalities, task conditions, and kinds of cognitive tasks. The modalities included verbal behaviors, speaking and writing kinds of messages, and nonverbal actions such as the wiring of electric circuits. The task conditions included students doing science investigations in laboratory and non-laboratory settings (experiments 3 and 13)*, children interpreting science phenomena in a "Piagetian" setting, (experiment 4), site-testing of people solving two kinds of electric circuit problems (experiments 2 and 12), in individual test situations, and lessons being taught in science classrooms (experiment 1). The cognitive tasks were of the problem solving, recognition, and immediate and delayed recall types.

The data for each set of observations of humans in each experiment were treated in the same manner. This involved treatments of 277 different sets of data. There were often subsets of data because some sets were treated with interaction codes, term analysis, and as non-verbal actions. An explanation of this is that set and subset treatments each involved obtaining 18 information measure values. If a Parakh-modified analysis of monogram, digram and trigram codes was done, there

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*The experiments are numerically coded to correspond with table entries and with descriptions in Appendix I.

would be three subsets; with each one being done to obtain information measure values. The series of experiments had a total of 456 treatment sets and subsets. The 18 information measures were calculated to determine the memoryful condition of the observed behaviors. Then another 11 information measures were calculated to determine behavior values in the memoryless condition.

Some cyberneticists regard an information measure value as analogous to a mean value. An information measure value does describe any one of the observed behaviors which was evidenced in a human processing a task. The study involved recording 44,935 verbal behaviors and 5,549 non-verbal behaviors. The information measure values were regarded as measuring the specified kind of information for any one event or action, and which was of a behavior executed by the individual who was being observed in an experiment. To put it another way, a particular measure is of the kind of information which describes any one of the actions made by the human being studied. The kinds of information measures and their meanings in the memory model are presented later.

A set of codes or events (non-verbal) was placed in a matrix so it could be used to determine information measure values. Several sets of data matrices from four experiments were treated on an IBM/650 computer. This treatment was done for the test of Markovicity. However, the cost of computer treatments became prohibitive A study was then conducted for finding the numerical relationships of information measures to a Markovian Chain. It was found that the H(x) measure was equal to the $H_x(y)$ measure at steady state. The difference between these measures is CODE or transinformation (26), and it approaches a zero value at steady state. However, steady state is only real in theory (27) and is not completely obtainable on a computer. As a square matrix (of say 30 x 30) is product-treated to higher powers, the i j row transition probabilities lose unity sums. This is due to a rounding-off of seven place decimal fractions. A numerical operation was constructed by which a memoryful matrix of data could be treated to obtain its steady state level. The CODE remaining when the steady state, memoryless, condition was obtained was then measured. The same computer-treated matrices were compared with the numerically operated calculations for steady state. It was found that the information measures of dependence did not differ from computer-obtained steady state matrix values by more than 00.17% to 1.76%. The operation rationale is based on the structural nature of a Markovian chain in an indecomposable condition and its exponential decay properties (27). The reader should keep in mind this derivation of information measure values and the treatment operations, because it has bearing on the "dependence strength" measure found in the description of the memory model. The implication will be established that a steady state cognitive processor is memoryless because coherence has gone to zero. It will be shown that intelligence is related to the memoryless condition or long term memory store components, and that information of a perception kind may still exist in such a condition.

Results

Preliminary Analysis

The human memory model described in this paper is very complicated. The complexity is acceptable to us because man's efforts to study cognitive processes of humans is recognized as being an historically insurmountable problem. The information measures which are used to describe memory processes and components involve complex numerical operations. These operations are, in fact, too involved to be described in this paper. The author is the prinicpal inventor for a patent (No. 3,611,313) which embodies these operations.

Considering these conditions for the proposed memory model, two approaches for describing it are herein presented. Appendix II contains a glossary of information theoretic terms. The second approach is a presentation of a simplified description (figure I) of the model and an over-simplified narrative of the components, and their actions, in the memory model. The reader is advised to carefully study either approach before proceeding to the findings. The reason for this advice is that the findings present corollaries of processes and processing-pathway differences used to accomodate behavioral and cognitive conditions found to ensue in the memory flow of information.

Narrative

The human is in an environmental setting. He (sic) perceives an array of real world objects. A series of $H(x)^a$ messages enter the short term memory store (STM)*. The messages are going to be "scanned" by an $H_y(x)^a$ unit which is "passaged" to the long term memory store (LTM)*, and where there is obtained a "gross" match of a "recognizer" for the input $H(x)^a$. The $Hy(x)^a$ unit "returns" to the STM and "scans" the $H(x)^a$ message. This is done by interacting with a released $H_x(y)^a$ message. The purpose is for a multi-level (3 levels) decision-making process. The $H(x)^a$ will be (1) allowed to decay because there is no "match" in the scanning process. The message will be filtered to obtain a CODE^a signal for transmission to the LTM (2) or to the STM (3) for another pathway flow treatment.

A filtering process occurs to form a CODE^a signal. The CODE^a signal is a "chunk" (8) which is transmitted to the LTM for the retrieval of "new" informational content. The "new" content is LTM-SS^a and is match-registered for "passage" on an output pathway. The match register seems to be an assimilative process which is used to obtain a REAL^a message, and involves some kind of combination of CODE^a and LTM-SS^a.

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[a] Denotes information measure in the narrative.

*The underlined STM or LTM "symbols" are used in this paper as abbreviations of short term memory store and long term memory store.

The CODE^a signal is used to "chunk" messages in the STM for an output of information messages. The "chunk" is an interaction of LTM-M^a and the end-product is of a feedback interaction with an LTM value called LTM-SS^a. The result is a REAL-M^a which is the useful information to be output as a message.

The output, H(y)^a, is "noisy" when it reaches the external world because of spuriousness operating through the output sensory system. The NOISE^a in the information processing channel is due to STM holding or to the lack of proper matches in LTM retrieval processing. The NOISE^a in the x message is usually lower than the NOISE^a in the y message in the STM or memoryful condition. The NOISE^a is at a maximum level in the LTM because there is an independence of x and y messages (in a sequence) when there is a search for a "new" message in the LTM memory file.

The H(x,y)^a unit in the STM "holds" proximity messages of x and y. The H(x,y)^a in the LTM is equal to the CODE^a signal in the memoryless condition. This is an LTM rehearsal process of a comparator mechanism for the match-register operation in the LTM.

The proximity relationships of messages in the STM are a function of the CODE^a signal. Some messages are of the attending behavior and most CODE^a signals for it are "destined" for an STM pathway treatment. In the case of monologues, the strength of dependence^a is low. When informational content is being treated the strength of dependence^a increases so that the relative CODE^a signal value is greater because the signal is being transmitted to the LTM.

Various ratio factors are flowing in the memory channels. These are of the H(x)^a, $H_x(y)^a$, CODE^a, REAL^a, and LTM^a. They are information levels for "match" purposes in the process of executing the development of a new output message from the memory.

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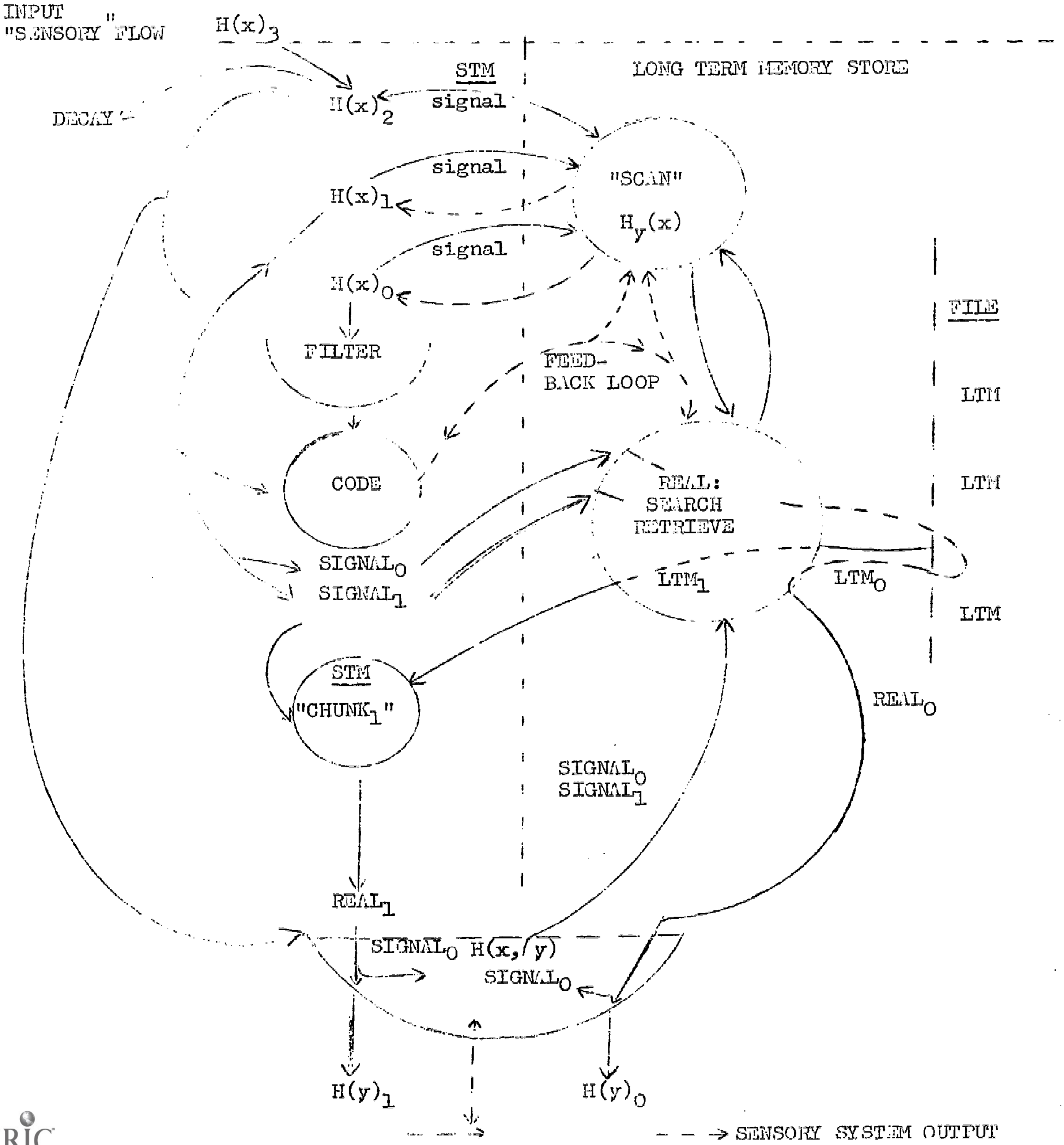
[a] Denotes an information measure in the narrative.

FIGURE I

DESCRIPTION OF MEMORY MODEL



Finding:01

The structure of an input message contains components which identify attentional behavior, the semantic nature of the message, and its' informational content.

The criterion measures are the strength of dependence between messages, the useful information (% REAL), and the error correction information factor $(H_y(x)/H(x))$.

Experiment one shows the last two criterion measures (see Appendix V). The error correction factor decreases as the structure of a message increases. In an ongoing input flow, the human identifies who spoke (monogram), whether it was question or statement inflection (digram), and what was the informational content (trigram). As the perceptional focus operates, the incoming message "obliterates" the uncertainty of the message being received. $((H_y(x)/H(x))$. The decrease of "noise" approximates a geometric function (.177,.095,.046 bits per input bit). This is probably of a phase space structure. The useful information (REAL) in a transmission channel is inversely related to the "noise" in a channel. Therefore, as the above-stated "noise" decreases in the increased structure of the incoming message, the REAL information normally increases (.456,.648, and .583 bitsper bit of shared information).

The strength of dependence between messages is a function of the content completedness of an incoming message and of the attentional behavior for the message. The strength of dependence increases from monogram codes, digram, and trigram codes (usually from an M^4 through an M^{256} power). Thus, as the attentional behavior "operates", the human executes a connectedness of the time-framed input of the discrete message components.

Additional evidence for the role of attentional behavior is seen in the data of experiment four (see Appendix I). Children aged 6,8,10, and 12 years were each placed in a room with an adult. The children were shown science objects, such as a radiometer, and asked to interpret it. Their messages were coded by the modified-Parakh category system (23). The amount of error correction information per bit of input information was calculated for the messages (see Appendix V). The eight and ten year old children processed less error correction information at every gram-message level (monogram,digram,and trigram) than was done by the six and twelve year old children. They processed one-fifth, 0.1038 bit, as much error correction information at the trigram level. They had only 0.5862 bit at the monogram level, as compared to 0.712 bit and 0.7461 bit for the six and twelve year olds. It was concluded that eight and ten year old children had an attentional behavior which was greater than the other two age groups engaged in interpreting concrete objects. It is possible the data indicate Piagetian maturational levels of children. This possibility is being studied in two experiments. These are of individuals and of groups of children from grades one through six. They are giving interpretations of the radiometer and of the ball-and-boat, or flotation principle.

Other evidence of the fractional structure of cognitive messages can be seen in experiment three which describes the dialogue of four tenth grade children who solved an abstract problem about an illness. (see Appendix I for a description.) Those data were coded in trigrams and in terms, and it was found that the two kinds of codes varied as to the lesser and greater amounts of error correction information being processed in topic treatments. By listening to the dialogue one can discern the reason for the differences. The degree of concept difficulty in the sentences spoken by the children corresponded to the level of information measure in term codes.

Finding:02

The code signal ratio is a function of the interaction of the kind of task being processed and the degree of the match between input information, and of long term memory error correction scanning.

The filter mechanism in the short term memory store is used to form a CODE signal. The signal serves as a template which enables the forming of an output message. The nature of the signal product, how the signal is due to an interaction between incoming information units and its "recognition" for being related to stored information was explained in the memory model description (page 7). The code signal ratio is interpreted as the size of the CODE signal information unit as compared to the input information unit; which is H(x). A ratio of .50 means there was one-half bit CODE signal formed for every bit H(x) input. The findings of code signal ratios for eleven experiments are listed in Appendix III.

The signal ratio was found to be a descriptor for the task being processed. Problem-solving tasks usually have a smaller magnitude of code signal ratios for each message. (Experiments 6,8,11,12,13). Recall tasks (experiments 7,9,11) are usually processed with larger code signal ratios. Free recall tasks have larger ratios than constraining recall tasks. Dialogues (experiments 1 and 4) usually consist of recall type tasks but vary as to the structure of messages being formed. For example, classroom dialogues (experiment one) have decreasing code ratios as the message structure is completed. On the other hand, a child being interviewed by an adult as he interprets a science object (experiment four), engages a problem-solving mode. In this case, the ratio increases as the structure of the message is being completed. Comment: the reader should note that digram codes of 8-10 year olds had a code signal ratio of 0.1884 bit and an error correction factor of .2209 bit (see finding number 4) for incoming messages. A digram code is in the form of either a question or statement. In finding one, we advanced the possibility that the information measures were indicative of mental maturation levels.

The code signal ratio which is processed during problem-solving tasks is also related to the degree of success obtained in the task. Children who tried to solve the parallel circuit problem (experiment two) and who succeeded, processed larger code signal ratios (ratios of 0.2835 to 0.3588 bit) than did children who did not succeed (ratios of 0.2345 to 0.2522 bit). The same general finding is seen in experiment twelve in which college undergraduates tried to solve parallel circuit and three-way circuit problems. Those who succeeded processed a larger code signal than was processed by the subjects who failed to succeed.

The same principle for interpreting code signal ratios is seen in recall - problem solving type problems. Experiment thirteen was of dialogues of groups of four children who were treating seventh grade science investigations (see Appendix I for the description). These treatments were scored for the degree of success the groups had in answering the questions in the investigations. Some of the children were grouped to do the investigation in a laboratory setting while others did the same one in an "isolated" setting, or without the science materials for doing the investigation. The code signal ratio was found to increase as there was an increase in the achievement score (see experiment 13, Appendix VI for average scores).

There is some evidence that the code signal ratio is related to learning. The subjects in experiment twelve were undergraduates who tried to solve electric circuit problems. If they failed to solve the 3-way circuit problem, they were given a ten-minute training. Ten subjects succeeded in doing the problem after training. Prior to the training each action processed a CODE of 0.2033 bit for each input message, H(x). The post-training actions processed a ratio of .03866 code signal per input message. On examining (see Appendix III) the change of signal ratios, it was found that failure actions had increased process levels for every group which received training. The implication is that CODE signal ratios increase as learning occurs, and that the increase must reach a threshold level for meaningful learning to be manifested. The relationship of code signal ratio to learning experiences is also seen in the data of experiment thirteen (see Appendix VI). The achievement scores of science investigation groups were found to be significantly correlated to settings for investigations and to the kind of topic being investigated. The interpretation was that children isolated from the laboratory experiments and children who were involved in a difficult topic (concerning seeds and the tetrazolium test) processed code signal ratios positively correlated with the score they earned. In both cases, the cognitive task required of the children was lacking in completeness and demanded "cognitive strain". It could be inferred that the signal ratio became more corresponding to the input and error correction as a means to "achieve". The reasons for the other groupings of students' messages in settings not being significantly correlated with achievement will be discussed later. Here it is sufficient to say those groups had higher code ratios and higher average achievement scores.

The CODE signal is transferred to the LTM, as previously mentioned, and it enables a search for the retrieval of stored information. In 1962, Landauer (28) found that the approximate maximum rate of transfer of information from the STM to the LTM is three to seven items per second. The studies we have conducted indicate that the CODE signal ranges from 0.02 to 4.9 bits every four seconds. This is an item rate transfer of zero to 30 items every four seconds; at a maximum rate of 7.5 items per second.

Finding:03

The strength of dependence between information messages seems to be more related to the perceptual coding of the external world than to any correspondence processes of stored information.

The evidence for the possible role of the strength of dependence is shown in Appendix VIII. It is not significantly related to achievement levels obtained by groups of children investigating science content (experiment thirteen). In fact, the greatest dependence (at M^{16}) is when the students had more information available to them from the text material or had concrete objects in the forms of laboratory materials.

The same phenomenon occurs for the semantic structuring of messages. The power at which a steady state condition is obtained increases as an incoming message builds. That is, a monogram gets to steady state at M^2 or M^4. The digram code reaches the memoryless condition at M^4 or M^{16} and the trigram reaches the same condition at M^{16},M^{256}, or $M^{65,536}$. These data are not reported in the appendix because the study of dependence is still in progress.

However, there is evidence as to how the strength of dependence is related to other memory model components (see Appendix VIII). The dependence between messages increases as the noise or spuriousness of the informational message increases. An increase in the dependence between the messages flowing in and out of the memory is accompanied by a decrease in the amounts of input and output information. This is quite logical because redundancy of message relatedness also means a decrease in the individual discreteness of those messages. That is, the "uncertainty" of independent messages paradoxically decreases as the adjacent messages have a greater strength of dependence between them. This principle is related to the flow of useful information in the memory model. It must be kept in mind that the model operates in units which are noisy and discrete. Thus, as the dependence strength increases, the useful information shared between consecutive messages decreases.

The strength of dependence factor is discussed again in finding four.

Finding:04

Error correction information is a memory component which operates as a comparator. The function of the error correction information serves a dual role in the memoryful and memoryless conditions. In the former it controls the filtering process for the formation of a CODE signal. In the memoryless condition, it operates as a "match" process. The error correction factor is influenced by the amount and content of input information; the potential for successful information processing is a function of the range of tolerance of the operational levels of the comparator mechanism.

The error correction component of the memory model is quite complicated. It seems to serve as a connection between the STM and LTM stores. One piece of evidence is that, in a memoryless condition, the value difference is usually an increase which is equal in bits of information to the decreased amount of REAL or useful information. Herein is also some evidence of the feedback role of $H_y(x)$.

The $H_y(x)$ measure is probably not a major control factor in the use of STM information production pathways. Appendix V lists regression analysis results for a comparison of the $H(x)$ and $H_y(x)$ measures in eleven experiments. The analyses were done to test the hypothesis that the input message is not directly corrected by $H_y(x)$ in the STM. It can be seen that a memoryful $H_y(x)$ was correlated with an $H(x)$ input message in only four of the eleven experiments. On the other hand, the memoryless $H_y(x)$ was significantly correlated to the input information in ten of the eleven experiments. Experiment six was the exception for having any correlation and it involved a chained monologue on an abstract topic (see Appendix I). The slopes (byx) for memoryless condition error correction information increased in every experiment. Notice that, excluding experiment six, the lower limit of $H_y(x)$ was 0.7235 bit (experiment eight) and $H_y(x)$ had an upper limit of 3.3539 bits; in the conduct of attentional behavior in science lessons (experiment one). However, in the chained recall experiment, the $H_y(x)$ value increased by only 0.4016 bit for each $H(x)$ input bit of information. The interpretation may seem spurious because the coefficient of correlation for the memoryless condition was not significant. However, the experiment had a mean $H_y(x)$ of 2.67 bits, much lower than those obtained by the same subjects in the other five experiments (numbers 7-10).

Another piece of evidence for the oddness of the information flow can be seen in the rate of error correction information per input at the memoryful and memoryless levels. The experiment was designed to be for a recall task and to repeat an earlier experiment (experiment five), in which the same content was used to flow through a chain of humans. However, experiment six data turned out to indicate it was processed by the people as a problem solving task. One could ask how a predesigned kind of task was not treated as that same kind of task by the subjects. The experiment had two chains of five subjects who listened to a five minute monologue of a colleague and then immediately "passed" it on to another person by means of a monologue. The first subjects listened to an audio-tape of the source content. One of the subjects who listened to the tape presented a monologue which was attempted on a long term memory basis. That human had a memoryful $H_y(x)$ of only 0.0223 bit and a noise factor of only 0.0064 bit per input. This was very low compared to respective averages of 1.3996 bits of $H_y(x)$ and .3576 bit for the group of subjects. In other words this person tried to learn a very abstract and foreign passage of information. Then, on having failed to do so, output a monologue which was of term message repetitions (79.9% conditional redundancy compared to 52.2% for the group average, see Appendix VII). The monologue was thusly received as a quite incoherent treatment and was consequently treated later as being a problem-solving task. The subject discussed here also operated an STM in a rather odd manner. The first link of the chain used an STM information LTM-M^1 of 0.3800 bit while the three persons who followed in the chain had an LTM-M^1 value of 0.1709 to 0.1753 bit. The LTM use of LTM-SS had values of 0.4695, 1.0983, 0.9521, 1.0849 bit information, from the beginning link through the subjects in the first four chain links. The fifth and last chain person processed an LTM-M^1 of 0.086 and LTM-SS of 1.3637 bits. Clearly, the first subject was operating with 44.73 percent of the LTM information being formed in the STM. Look at Appendix IV , which shows the proportions of the LTM processed in the STM. Notice that 45.3% of the LTM processed in the STM was done in a classification sorting experiment (11) which involved problem-solving,recognition type tasks.

The foregoing interpretation is an analysis of how the error correction operator relates to the input messages (H(x)) in the memory model. We shall later show how error correction is related to the mental ability of humans (Finding:06). There is a threshold level at which error correction begins to "correct" input H(x), information. We devised a unique system to isolate the levels of variance which operated for the activation of the error correction unit. The results of the analysis are shown in Table I . The a_x coefficients for regression analyses (from results shown in Appendix V) were used to determine the amount of input information which could be input before the error correction unit became active. Then the "variance" of input which could be error-corrected before the average information input level was obtained in the memory. This system for analysis enables an approximation of the degree to which $H_y(x)$ corresponded to the input information.

The analysis devised to study the error correction component is quite logical when it is known that a memoryless condition has an error correction measure which, when the slope of error channel region of $H_y(x):H(x)$ is calculated, operates at a slope of 1.03 bit $H_y(x)$ per bit of $H(x)$ information. The reader who wishes to study this principle should read finding five before continuing this section.

Please examine Table I. As the input information decreases there is a level at which the error correction component "shuts off" (see columns one and three). The decrease is from the average $H(x)$ and occurs in all but one of the experiments. The exception is for the digram code of experiment one. Keep in mind that the average teacher talk for the 30 science classroom dialogues was 70 percent and the digram identifies the semantic structure of a spoken message. The degree of the change of the $H(x)$ value is shown in columns two and four. These figures have the same signs as corresponding entries in the respective columns.

There are several observations in the results of degree of change for threshold levels of error correction:

(1) Children who failed to solve problems (experiment 2) had an error correction unit which was probably not operating any differently in a memoryful condition or in a condition where x is independent of y in the LTM. The contrast is different for successful solvers, and it probably means these children used

the LTM storage to solve the problem. This observation is suggested in section five.

(2) The same situation occurred for children interpreting phenomena. Their attentional behavior (monogram in experiment 4), like failure in problem solving, probably did not have much operation of the LTM.

(3) The $H_y(x)$-SS probably has a tolerance range which is related to the comparator mechanism proposed by Sternberg (29). The experiments differed in their experimental setting and design (see Appendix I). We can easily compare memoryless tolerances in terms of what is known about the performance behaviors in the experiments. Higher levels of tolerance occurred where humans attempted to balance their learning through input information and retrieval information. Experiments 5,9, and 13 verbally processed and involved an individual confronted with a task to perform. These high ranges of tolerance are contrasted with ranges in experiments 2,4,8 and 10 wherein the subjects had some permanent information existing in the experimental environment.

These observations indicate that the lower the tolerance range operating for the input information, the closer is the match for the correction of that information.

The analysis was continued by studying the ranges of changes in the average amounts of $H_y(x)$ measures which occurred for the changing from memoryful to memoryless conditions of information processing. The numerical operation was expressed as $H_y(x)$-SS minus $H_y(x)$-M^1. The bit differences are shown in Table II. The same table shows the strength of dependence for messages at a 16th power level of code signal.

TABLE I

Threshold Levels for the Activation of the Error Correction or Comparator Component

Experiment	Memoryful Input Change		Memoryless Input Change	
	BITS	%	BITS	%
(1) Classroom Dialogues				
Monogram	-0.0376[a]	4.80[1]	-0.0965	12.32
Digram	+0.0844[b]	5.07	-0.0713	4.28
Trigram	-0.2690	9.65	-0.1106	3.96
(2) Electric Circuit				
Success	-0.2587[c]	9.37	-0.7696	27.89
Failure	-0.8034	27.95	-0.8765	30.50
(4) Interpretation of Phenomena				
Monogram	-0.2910	20.36	-0.3715	25.99
Digram	-0.1991	8.89	-0.2818	12.58
Trigram	-0.5053	15.05	-0.3381	10.06
(5) Conceptual Level Test	-0.8034	35.83	-0.3765	39.09
(5) Chained Recall #1			-2.4610	63.07
(7) Delayed Recall			-1.9024[c]	44.79
(8) Abstract Problem Solving			-1.4297	33.44
(9) Recall of passage			-2.4036	59.98
(10) Recall (free)			-1.6857	35.15
(11) Classification Sorting			-0.9945	25.91
(13) Conducting Investigations			-2.6516	65.95

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[a] To be interpreted that $H(x)$ can <u>decrease</u> 0.0376 bit before $H_y(x)$ operator activates

[b] To be interpreted that $H(x)$ can <u>increase</u> 0.0844 bit before $H_y(x)$ operator activates.

[c] Significant at 10% level of rxy significance.

[1] To be read that $H(x)$ changes 4.80 percent from where $H_y(x)$ begins, until the "average" $H(x)$ occurs. Viewed as variances for operation of error correction information.

The tolerance range of the operation of error correction roughly approximates the amount of change between memoryful and memoryless conditions. This observation fails to apply to situations where the $H_y(x)$ factor is related to external world exigencies. The larger amount of $H_y(x)$ change occurred for such situations (see experiments 7,9,10, 11 and 13b and 13c). In all cases the subjects wrote their responses to external stimuli or had objects in the external world with which they were interacting (experiments 7,11 and 13b and 13c). This relationship of the error correction unit matching a recognition of the input information from the external world is exemplified by two of the experiments. In experiments two and eleven,the subjects were treating situations in which the objects of the environment needed to be interrelated (see Appendix I). Notice that these two tasks had the greatest strength of dependence (2.4400, 1.4067, and 3.7340 respectively). The literal translation is that the "perceptional" relationship between x and y outputs was greater when the real world objects had a perceived degree of permanence. The potential for succeeding in solving the electric circuit problem is seen in comparing the change of error correction information levels and the strength of dependence. Those who succeeded in solving the problem (see experiment two) had a range of $H_y(x)$ change similar to those who failed but they maintained a greater strength of dependence until the steady state or memoryless condition ensued. How did they do this? The CODE signal ratio (see Appendix 3) was greater, a greater amount of the new information (ITM) was retrieved from the long term memory store (see Appendix IV), and they had a greater differential for the activation of the error correction unit between the memoryful and memoryless conditions (see Table I).

One needs to keep in mind that the interrelationships of the strength of dependence and the error correction change interact with the input information. This consideration is seen in the findings for tables one and two; for experiments nine and ten. The recall tasks were studied by the modality of the subjects writing either what they had heard (experiment 9) or what they knew (experiment 10). In both cases, the responding subjects could "check" on the nature of their statements by reviewing what they had previously written. These strengths of dependence were both very low and did not appreciably differ from each other. One of the experiments involved the subject attempting to recall what he or she had heard (experiment 9) and the other experiment (10) was one wherein the subject utilized what they knew, which was from previous learnings. The distinguishing factor was found in the tolerance range for the activation of the error correction of the input information. As shown in Table I, the subjects who were trying to recall what they had heard operated a greater tolerance range. On the other hand, the humans (same in both experiments) who had to match a large amount of <u>LTM</u> information retrieval to what they stated in the external world, had a decreased tolerance range. This interpretation of relationships enabled a conclusion that the use of the error correction match register of the long term memory store decreases in the range of activation tolerance for an increased efficiency of the retrieval of new information from the long term memory store. This sequence is supported by the proportions of the LTM which originate from the long term memory store (see Appendix IV).

TABLE II

The Range of Error Correction Information Between Memoryful and Memoryless Levels*

Experiment:	Bit Change from Memoryful to Memoryless* Condition	Average Dependence at the 16th power, expressed in negative three exponents
(1) Classroom Dialogues		
Monogram	+0.1350*	.0458
Digram	+0.3715	.0973
Trigram	+0.0450	.0347
(2) Electric Circuit		
Success	+0.7113	2.4400
Failure	+0.6756	1.4067
(4) Interpretation of Phenomena		
Monogram	+0.1680	0
Digram	+0.1400	.2325
Trigram	-0.1750	.1958
(5) Conceptual Level Test	+0.4410	.5934
(5) Chained Recall #1	+2.2220	.0472
(6) Chained Recall #2	+1.2704	.0264
(7) Delayed Recall	+2.1733	.0209
(8) Abstract Problem Solving	+1.5384	.0210
(9) Recall (of a passage)	+2.2376	.0127
(10) Recall (free)	+2.6932	.0006
(11) Classification Sorting	+2.1958	3.7340
(13) Conducting Investigations	+1.2237	.0593
a) Non-lab. (av. score=51.2)	+1.1172	.0560
b) Lab. (av. score=89.4)	+1.3313	.0626
c) Anatomy topic (av. score = 90.6)	+1.5416	.0270
d) Seeds topic (av. score = 70.0)	+0.9065	.0916

*1-Calculated as mean $H_y(x)$-M^1 subtracted from $H_y(x)$-SS mean value. To be read as an increase of 0.135 bit $H_y(x)$ from $H_y(x)$-M^1 to $H_y(x)$-SS

Finding:05

The output information which is "new" is the REAL information in the memory model, and is a function of the interaction of the CODE and LTM information processes The LTM information measures constitute the "new" information formed in the STM, as a consequence of a "chunking" process, and in the LTM of the LTM, which identifies the "new" information retrieved from the long term memory store.

The REAL information is a common information theoretic measure (30,14,31,18). It is defined as the useful information shared between two consecutive messages, and is sometimes called mutual information (32,33). The algorithmic approach for the REAL measure is that it is the sum of the CODE signal and the LTM measure values. The CODE signal is also called transinformation (26). It has not been recognized of "value" to other information theorists. As described in finding number two, it may be the "chunking" factor hypothesized by G. A. Miller (8). The LTM information measure was derived by the author of this paper. It has a quite logical meaning. If an input message is coded, that process probably occurs in the short term memory store (34). The CODE signal not being the "new" information, is the signal template for identifying (match-search) new information, which is to be retrieved from the long term memory store. That process does not account for the task information processed mostly in the short term memory store. Nor does it represent the "new" information retrieved from the long term memory store. It has been hypothesized that the REAL information represents the new information retrieval from the long term memory store. However, a mathematical analysis of the REAL measure shows that changes of information values from memoryful to memoryless conditions do not identify REAL-SS as being equal to the CODE-M^1! The CODE measure value is equal to the value change for the information shared, H(x,y), between two consecutive messages; as the system goes from a memoryful to memoryless condition. The REAL information in the memoryless condition has a change value, from the memoryful condition, equal to the LTM measure value! The relationship is quite logical. The onale is that a message output from the short term memory can be a chunking process where the CODE plus the LTM-M^1 value is the REAL-M^1 value. However, there is no CODE in the long term memory store and the "assimilated" information (6) is the information retrieved from the long term memory store. This is the LTM-SS or REAL-SS which are of the same information value!

The reader may now ask the meaning of the LTM information measure in the short and long term memory stores. It is quite simple. The LTM-M^1 is the new information in the short term memory store, and the new information is the configurational change in structure resulting from the chunking process, or the result of an interaction of the CODE and LTM-M^1 measures in order to develop a short-term memory store REAL output message. The LTM-SS measure is the REAL-SS information, and results from a retrieval of new information from the long term memory store. The retrieval information is combined, or assimilated into, the CODE signal to form a REAL message output.

The findings presented in this section support those previously reported in this paper. That being the case, the presentation will be less explanatory.

The amounts of the LTM measure values found in the STM and LTM are listed in Appendix IV. There was no monogram or attentional behavior information retrieved from the LTM (experiment one) and this supports the contention of the building structure of a message. It is an interesting observation that the LTM memoryless new information increases to a level of 65.85% at the trigram level, and that the increase is by ten percentage point increments. The latter aspect again supports the finding (in the preceding section) of the "geometric" structure of semantic messages. The trigram REAL information for the study of 30 science classroom dialogues was reported at the 1971 NARST Conference (Moser). It was constructed of 1.096 bits CODE and 1.5125 bits of LTM, and the M^1-REAL message had a value of 2.609 bits. As the proportion of teacher talk increased the code value decreased and the LTM-M^1 increased. The end-product of REAL information was 2.545 bits for less than 70% teacher talk and 2.658 bits for teacher talk of more than 70%. The

90-98% teacher talk level had an average 0.611 bit code, 2.373 bits LTM-M^1 and 2.984 bits of REAL information in trigram messages. As shown in Appendix IV, the trigram code involved a decreasing amount of "new" information (LTM-SS) as there was an increase in the amount of teacher talk in the science classrooms. This is quite expected when one considers the "speaker" is the teacher and eight to nine out of ten of the messages came from that human memory. Much like it is seen in experiment 11, the "speaker" was processing many messages through the STM. These messages were of higher dependence and in some of the chain of x and y messages were "chunks" of STM site messages.

The hypothesis of LTM information being of STM and LTM sources is quite in accord with the McAdam and Whitaker (35) discovery of a memory message forming up to one half second prior to its being spoken by a human. Messages are coded every four seconds in the collection of classroom dialogues. The average output of a 90-98% teacher talk message, H(y), carries 3.9949 bits of trigram information. That is about 16 items every four seconds,or about 4 items per second. A human speaks at a rate of about one and a half to two words per second for a sentence presentation. The information of a monogram at the 90-98 percent level of teacher talk carries about 1.48 bits of H(y) information. However, there is no LTM monogram information retrieved from the LTM. We see this as the structuring principle operating to embed the monogram information into the trigram message. The difference is 2.5149 bits of REAL information. This is probably the trigramic information found in the LTM (proof: 2.5149/3.9949 bits = .6295). These 6 items ($\log_2$ of 2.5149 bits) are transferred to the STM and when "mixing" with the STM inventory of messages constitutes the STM load of 5-9 items discovered by G. A. Miller (8).

The short term memory store processing of information is seen as related to the kind of task being processed in attentional behavior and the nature of the mental maturation of the human who is doing the cognitive task.

Please examine Appendix IV. Notice that classification sorting of geometric shapes and colors of figures by adults (experiment 11) involved a retrieval of only 10.22 percent of the LTM information from the LTM. The task was one in which 45.3 percent of the LTM was in the STM. This is a "recognition" type of task which was presented in a problem solving mode. The memoryful information ratio is quite like that of monograms and digrams of 30 science classroom lessons (50.04% at the 90 to 98 percent level of teacher talk).

The successful solving of a problem is related to how the new information is formed in the STM. It has been mentioned the children of grades one through twelve tried to solve an electric circuit problem in experiment two. The children of the elementary grade level who succeeded, retrieved 77.23 percent of their LTM information from the LTM and processed only 14.03 percent of the LTM in the STM. The secondary school children who succeeded had only 24.26 percent of the LTM as new information from the LTM and 42.23 percent of the LTM information was processed directly in the STM. So we could conclude that the children of an elementary grade age succeeded because they had information, learned from previous experiences, which was stored in the LTM and could be retrieved from the LTM. The adolescent humans successfully solved the problem by a "balanced" retrieval of LTM information from the LTM and by using the STM type of LTM information. This is seen in contrast to adolescents failing to solve the problem because of a lesser amount of information being retrieved from the LTM, too much STM information processing, and too low a ratio of error correction information (.5698 bit compared to .6297 bit). The latter process can be seen as affecting the filter process and too low a code signal ratio being formed (see Appendix III) to be used for the efficient retrieval of LTM information in the long term memory store. These findings for a problem solving task are quite indicative of the differences of chronological or mental maturation levels. It seems that formal operational people try to process problems by a greater use of the short term memory store. The amount of "learned" information utilized seems to be lower for these humans. The claim that the data shown in Appendix IV is indicative of the occurrence of learning is an intriguing one. If we can identify the amount of LTM information processed in cognitive tasks of problem solving, this information could be invaluable in the improvement of education.

Examine the LTM information processing done by college undergraduates (experiment 12) who tried to solve two kinds of electric circuit problems. Notice that only one group had any new information retrieved from the LTM. That group failed to solve the 3-way circuit problem even though they had 25.07 percent of the LTM originating as "new" information from the LTM. Their "problem" was that they had a CODE signal ratio (see Appendix III) of about one-half the amount for an efficient retrieval needed to successfully solve the problem. This group of humans did this problem-solving processing prior to any training. They then had a ten minute training on how to solve the problem and, on attempting the problem again, failed to solve it. In this instance no "new" information originated from the long term memory store. Two things could have happened to explain this observation. It is possible that the information used to solve the problem before training was "incorrect". The second and more plausible explanation is that the humans were taught to process the problem as an STM type of LTM. Think about it as that ten minutes of training is too short a time to learn to solve such a problem and look at the fact that these humans increased the STM proportion of LTM from 42.86% to 62.70%. So they were "taught" to study the changes in the external world and that no "learning" occurred in the training. The evidence which supports the use of the wrong information for solving the problem is seen in the finding that the humans had succeeded in solving the parallel circuit prior to their failing to solve the 3-way circuit, and before the training. It is possible the humans tried to equate the way they successfully solved the parallel circuit problem to the attempt to solve the 3-way circuit problem, and that the "new" information retrieved from the LTM was of a parallel circuit but not of a 3-way circuit problem. Evidence supporting this is seen in the finding of ratios of 0.6494 LTM (STM) for success in solving the parallel circuit problem by another group was comparable (0.6675 LTM) for the group of humans being discussed.

The issue of the use of "learned" information in contrast to a major role being played by the STM is exemplified in the data of experiment twelve. The first indicator is that training did not result in any "new" information being retrieved from the LTM. The second observation is that the role of the STM usually increased after training. A concomitant observation is that the CODE signal ratio (see Appendix III) increased after training. However, the CODE signal ratio was not to a level comparable to successful problem solving of an electric circuit in experiment two, unless it was that the humans succeeded to solve the problem. So the issue becomes one of that the humans were "taught" to solve a problem in the ten-minute training they received. However, the training was to utilize the STM for relating consecutive messages to each other. This is probably not real learning.

There is other evidence that humans vary in their use of the STM, and that it is a function of their age and of the task they are processing. This is seen in experiment four (Appendix I), wherein children interpreted science objects as they were observed or interviewed by an adult. We previously reported the phenomenon of age differences being related to memory processes (see finding one). Here the phenomenon is seen as being related to the role of the short term memory store. The trigram LTM in the STM was found to be indicative of the relating of the STM to the external world. We claimed that (in finding one) concrete operational children differed in their use of the memory. In this section the evidence seems to indicate that eight and ten year old children made a greater use of the STM for processing the informational content of messages (trigrams) than was done by six and twelve year old children.

The final proof of the validity of finding number five is that humans have a long term memory model which operates on the task being processed is seen in experiments six through eleven (Appendix IV). Keep in mind that the same group of graduate students participated in the six experiments (see Appendix I for description of the experiments). This design enabled us to examine the memory functions of the same humans in the processing of various kinds of cognitive tasks. The reader can better understand the role of the LTM information measure by numerically ranking the proportions of LTM utilized as the "new" information retrieved from the <u>LTM</u> and the proportion of the LTM measure value which was operating in the <u>STM</u>. The "new" information retrieved from the <u>LTM</u> can be seen as closely related to the task presented to the humans and not as related to the kind of cognitive task they are processing The greatest amount of <u>LTM</u> "new" information was retrieved wherein the humans were asked (experiment 10) to relate what they knew about science learning. This is a free recall task. The subjects retrieved the least amount of "new" information when they sorted objects perceived from the external world (experiment eleven). The second largest role of the "new" information retrieved from the LTM was when the humans were asked to immediately recall the content of a passage spoken to them (experiment nine). The next greatest operation of the retrieval of information from the <u>LTM</u> occurred in two different experiments (numbered seven and nine). One was to recall content heard five to thirty-five minutes after receiving the information (experiment seven) and the other was to solve a legal problem about incestuous activities (experiment nine), wherein the subjects possessed a written statement of the problem. Notice that the tasks differed and that the input information into the <u>STM</u> differed by being verbal and written. Herein we have an intercept for learning (experiment seven) a recall task and the processing of a problem solving task (experiment nine). The equated comparisons of the role of the LTM is that it operates on a threshold level which is closely related to the error correction comparison with the information received from the external world. However, the threshold is influenced more by the error correction component (see Appendix V) than it is by the code signal (see Appendix IV). We have, therefore, identified the intensities of the roles of the memory model components in the processing of cognitive tasks. These findings are supported by the threshold of the error correction unit evidence presented in finding four.

These observations of the existence of the LTM in the STM and LTM are quite conclusive. However, they seem to indicate useful information more closely related to the informational content being processed and to the task perceived by the human than to the human intellect. The LTM measure is also related to successful information processing, but we believe the relationship is secondary to some other information measure. These beliefs will be discussed in the conclusion section.

The reader should now understand the roles and complexities of the interactions of the memory model components. The criterion tests for the model have thus far been examined for internal relationships. It now remains to establish the validity of the model with respect to external criteria, such as the intelligence of humans and the levels of their achievement in processing real world experiences.

Finding: 06

The information processed in the human memory model is related to the intelligence of individual humans and to the degree of success humans have in processing environment experiences.

The two external variables, mentioned above, are probably more appropriately called criterion measures. The measures were the Miller Analogies Test and scores earned by groups of seventh-grade children who solved investigations (see Appendix I for a description), as they were located in a laboratory or were isolated from the laboratory. The scores were assigned by three science teachers who listened to the dialogues of the groups.

The external criterion measures were not tested against information measures as a means to determine how well the memory model components "measured" the intelligence or achievement ability of humans. Even though such an application may seem to be the obvious motive, the objective for using criterion measures was to obtain a means for classifying information theoretic measures as to their primary and secondary cognitive roles. The objective was then one of studying how the memory components operated with respect to non-information theoretic kinds of cognitive measurements. In other words,these tests were done to find out how memory components were or were not related to other measurements of memory processing.

Regression analyses were done for tests of rectilinearity. Coefficients of correlation were then calculated for the significance of relationships between information measures and the "external" measures. Significant correlations were recognized at the five and ten percent levels. In cases where the discussion is about external measure correlations having cognitive meanings, we shall restrict the claims to five percent levels of significance. The ten percent level was accepted for using slope levels and regression coefficients to study the interactions of relevant information measures in the memory model. In this section our presentation will thus refer to indirect relationships and direct relationships between variables, and we will not use the term "significant correlation". This is done because of the specified purposes of our analysis. The regression equation type of statistic was selected because information theoretic values are stochastic and so too are regressions function measurements of the stochastic relationships of variables (36).

The regression analysis results are listed in Appendix numbers VI and VII. There were 110 analyses completed in the study. Twenty-nine were found significant at the five percent level and another fourteen were significant at the ten percent level. These significant tests were 26.4 percent and 12.7 percent, for the respective percent levels. Thus the tests which were significant represented 39.1 percent of the 110 tests conducted. The n of significant product moment correlations indicated (37) that the p of the information theoretic measures were related to the criterion measures; operated as a real correlation between these variates. It also indicated that the relationships were not spurious.

The scores of the Miller Analogies Test and the achievement scores are not measurements of the same cognitive processing. The former is a type of test for measuring the intelligence of adults, whereas the achievement score is of the degrees of success obtained in a problem solving kind of task. It has been claimed (38) that the MAT is a verbal analogy kind of test. The author consulted with psychologists at the University of Pittsburgh in order to determine the kinds of cognitive tasks involved in completing the test. The consensus was that it involves recognition and recall task processing, with some problem solving processing occurring at times. In the opinion of some psychologists, it is some kind of indicator of the intelligence of adults. The two measures may not serve as correlates to the same construct aspects of the model. As previously claimed, the achievement scores for experiments were more found to be corresponding with the external environment. On the other hand, the MAT, being a measure of intelligence, may be more correspondent with an "internal environment". The analogy could be that the two criterion measures correlate with measures of different components and different processes in the memory model. This should be kept in mind while you read the narrative of the test findings.

Two experiments were found not to have relationships of information measures with the MAT. These were experiments 9 and 11, and their test results are listed in Appendix VI. The experiments involved two different kinds of modalities, with the immediate recall experiment consisting of an auditory input and a written output.

The classification sorting experiment involved a visual input and the same kind of output. There is considerable evidence that the sorting experiment involved the STM as the site for the processing of nine-tenths of the LTM information. It is somewhat difficult to account for the lack of a correlational relationship by the immediate recall experiment information measures. The explanation seems to be that the subjects listened to a five-minute passage and immediately "related" what they had heard. It is possible that they did not effectively correspond what they heard with the long term memory output, thereby producing information measure values which were not compatible to an "operating" memory. This possibility is raised because the written messages they "recalled" contained few statements like those they originally heard. Those which were similar consisted of facts of a numerical kind. Few recall passages contained statements of the principles which were originating from the source. We are currently studying the data of these experiments by testing for relationships of the other information measures, i.e., noise in y, H(x,y), H(y).

The values for information measures of each kind were "averaged" for experiments six through eleven. These averages were tested for relatedness to the MAT. it may seem quite improper to do this kind of averaging. However, the same subjects participated in the six experiments. So the averaging was done to obtain the "average" amount of information processed by each human who had participated in the experiments. The regression analyses were then done to test the relationship of the information, processed by a human memory, with the MAT score. Three information measures were found to be related to intelligence (at a five percent level). These were the error correction information, CODE signal, and REAL information ratios at the memoryful, or STM, level. The data making up the "averages" were then partitione back into the respective recall and problem solving types of tasks. Three experiments were a priori assigned to each class of tasks. Regression analyses of these two classes (average recall and average problem solving) showed the MAT was not significantly correlated with any average information which was processed in a problem solving task. Three information measures were, however, found related to the MAT for recall task averages. The elimination procedures showed a possible interpretation for the human memory strategies in processing cognitive tasks. The conclusion was that <u>problem solving task processing is not as closely related to "intelligence" as is the processing of recall tasks.</u>

We were not surprised that the "average" information processed by humans solving different kinds of problem solving tasks was not correlated with the MAT. According to Barron and to Berelson and Steiner (38,39), problem solving and creative thinking are not very related to verbal intelligence. The reader should note that we did not include the correlations of "average" information in the aforementioned probability count for the reliability of the comparison tests.

The six tasks were then each examined as to the relationships of information measures with the MAT. There were 16 significant correlations in the two remaining kinds of recall tasks and only eight in the two remaining problem solving tasks. It was again concluded that the MAT score was more closely related to information processing in recall tasks.

The sign differences for coefficients of correlation were quite uniform. The memoryless filtering system and the information found in the STM was directly related to the M.T. The error correction unit of the memoryful and memoryless model areas were found to be indirectly related to the MAT. The sign direction which varied for information measure relationships were found to be limited to the CODE signal ratio and to memoryless error correction information. The changes in direction signs for relationships are explained in the description of the feedback system (see page 44). However, because the comparison of the $H_y(x)$-SS measure was across the two sets of experiments (6 through 11 and number 13) we could not test their independence. The three significant CODE signal ratio correlations were given a Z-test (40). The chi square test value was 0.8658, for two degrees of freedom. It was concluded that the CODE signal ratios were of a common population. The changed sign direction was different for the problem solving CODE signal ratio (experiment 8) but the similarities of the three ratios is seen in the slope values (byx in Appendix VII). It was concluded that the CODE signal ratio processor is related to the cognitive factor but that it varies as to the kind of task being processed (see page 12 for an explanation).

The next comparison was of experiments six, seven and ten. The first two experiments involved immediate and delayed recall tasks used for the processing of a common content. The relationship of the two memory information flow tasks did not differ from each other, with respect to the MAT, in the following measures: $H_x(y)$ RE, REAL-M^1, % REAL-M^1, NOISE IN x-M^1, and $H_y(x)$-M^1. They did differ in that the immediate recall task was related to the MAT with respect to the CODE signal and the $H_y(x)$-SS information measures. The delayed recall task differed from the immediate recall task as it processed a CODE signal ratio which was related to the MAT. Experiment ten involved a "free" recall task wherein the subjects were to "tell" what they knew about science learning. This task differed from the two others in that it was significantly related to the MAT through the H(x) R.E., and the % LTM-M^1 information measures. It was found that it had a commonality with the other two tasks with respect to the H(x)y-R.E., REAL-M^1, % REAL-M^1, NOISE IN x-M^1, and $H_y(x)$-M^1 information measures. The "free" recall task was related to the immediate recall task but not to the delayed recall task. This processing was found to be the CODE signal information measure.

The three experiments involved three different kinds of processing strategies for tasks. It is important to keep this in mind. The same content (see Appendix VII) was operated upon by the same individuals in experiments six and seven, and there were discriminators found for them. However, the discriminator involved only three model components. A literal interpretation is that a problem solving kind of immediate recall is distinguished by the LTM error correction factor and by the CODE signal used for retrieving a message from the LTM. The "learning" of an external world experience is distinguished from immediate recall by the CODE signal ratio used to retrieve an LTM message. The use of information, and not recently experienced, involves the use of the redundancy in an input information measure ((H(x)) and the ratio of the memoryful LTM information being processed in the STM. These memory components are those which are related to the intelligence of the human. We can conclude that the role of the intelligence, for the degree of neural structure of the human, has been isolated as to the intellect control in the processing of tasks.

The relationships for human intellect control of memory information processing has been partially studied by Hsia, who calls it selection power (18), and by others (14, 17 and 41). The simplified descriptor explanation is that the LTM operates on a feedback basis by which non-environment-related processing activates the redundancy of sequences of messages; which are output by the same memory (of a human). A code signal is formed for this input relationship and this operational process is monitored by the STM information chunks. In this memory flow, the information retrieved from the LTM is controlled for a maximized output of stored information (see Appendix IV, experiment ten, where it was reported that all of the LTM information was "new" information retrieval from the LTM).

The learning of information in new experiences involves the use of a CODE signal. This CODE signal does not differ by its ratio to the input message (see Appendix III) but does differ in the strength of the feedback of the memoryful error correction factor (see Appendix V for the difference of the levels of significance of $H_y(x)-M^1$; for experiments six and seven.)

The final aspect of the study of the relationships of external criterion measures to memory model components was the flow of information; which was related to the degree of success in solving science investigations (experiment 13 in Appendix VI). That experiment had 19 meaningful correlations out of 35 tests. The 12 correlations with values exceeding five percent levels of significance constituted 34.3 percent of the population of tests.

All but two of the experimental design correlations were found to be for the non-laboratory setting and in the treatment of the topic on seeds. A study of the description of the experiment variables (see Appendix I for the experiment description) and the average scores earned indicate these two conditions were the ones which gave the subjects the least amount of information with which to complete the investigations. We could conclude these tasks were processed with a greater efficiency for cognitive application. This claim is supported by the consistency of the significant correlations these conditions had with the achievement scores. The non-laboratory setting and the seeds topic treatment had significant correlations for the CODE signal ratio, REAL memoryful, for the NOISE IN x memoryful and memoryful error correction information measures. The interesting aspect of these findings was that these same measures were found for the three experiments (numbers 6, 7, and

10), which were discussed for the consistency of measures related to the MAT. Herein then is additional evidence for the intelligence of humans being strongly related to particular memory model components.

The design conditions of a laboratory setting and in the treatment of the anatomy topic had significant correlations which were again explainable in terms of the same measures being related to the MAT. The treatment of the anatomy topic involved the study of the digestive system of the frog. We interpreted this topic treatment in finding:02. It was reported, in finding number four, that the error correction information operated in different pathways for the treatment of the seeds and anatomy topics. The claim was made that the seeds topic was largely treated by the memoryful error correction (see Appendix IV) information and that the anatomy topic was treated more so in the memoryless condition. The same relationship for the immediate recall experiment (number six) is believed to mean that the $H_y(x)$-SS factor may have some relationship to the storing of information in the LTM. This claim is supported by the fact that the subjects (experiment 13) who were isolated from the laboratory possessed a picture of the anatomy of the digestive system of the frog, whereas those in the laboratory actually dissected specimens. In both cases, the subjects had an information flow from the external world which could have been "learned" and by which they later received a score for answering the questions of the investigation.

The final finding in the experiment on investigations is concerned with the conditions for achievement scores and with the information processed by all 20 groups of seventh grade children who participated in the experiment. Nine of the 17 correlation tests were found to be significant at the five and ten percent level. The input information and output information messgae values were found to be directly related to achievement. The memoryful error correction measure was not found to be significant, even though it was for the isolated groups of children and for the treatment of the seeds topic. Another important finding was that the information shared between an x and y sequence of messages was directly related to achievement. The various design groups, by "laboratory" settings and topic treatment, were not tested for this relationship.

The most intriguing finding in the regression analysis study was one for which we have no plausible explanation. Examine the REAL information measures for the six experiments, in Appendix VII, and for the science investigations experiment in Appendix VI. Consider the possibility that we can use regression analyses to isolate the information in a memory when there is no influence of the external world input, or of the intellect structure of a human memory. The experiments averaged an 86.62 percent for the information processed in "average" problem solving tasks; as the processed' information operated in the LTM. The investigations in experiment number 13 had 85.40 percent of the information operating in the long term memory store. These values of information are quite similar. The "new" information, retrieved for average problem solving tasks in the set of "six experiments", constituted 84.55 percent of the LTM measure value, and 82.29 percent was "new" in experiment thirteen. This is evidence that the human transaction of investigations had information being processed like that found in problem solving task.

Consider the REAL information measure for the memoryful condition. Look at the ay regression coefficients in Appendix VI and Appendix VII. This value is interpreted as the useful information flowing in the memory when there is no"relationship" with the intellect or with the achievement success factors. The value of 1.55 to 1.76 bits of information remains in a memory, which is theoretically not related to the intellect. The treatment of these values in this way needs to be cautiously approached. The classic study for the consideration of information at zero MAT score or achievement scores would be to study the information measure values processed by a human who had a score of zero. That, of course, is not possible.

We have tried an approach by measuring the information carried by verbalized term messages of an adult before and after he became inebriated. The information he processed while drunk had more noisy channels and the channels "carried" less REAL information.

The mystery of REAL measures at zero variable levels is more intriguing as additional relationships are studied. The 1.5814 bits of REAL value at zero variable (x) in experiment thirteen is much like the values of 1.7564 and 1.5675 for experiments seven and ten, and like sub-population values in experiment thirteen (1.5477 and 1.5827 bits). The intrigue advances when it is known that the <u>average</u> REAL value for the messages processed in the 30 science classrooms (experiment one) was 2.609 bits and the LTM-M^1 value was an average of 1.519 bits. These values are all for the memoryful condition. Now consider the REAL values for memoryless levels of zero variable (x) for the "average" of recall experiments (see Appendix VII). The value was 1.4494 bits. So, there is some evidence for the REAL information measure being a component which operates on a transfer basis between the <u>STM</u> and <u>LTM</u>. It may be that the isolated REAL values we are observing are common and are probably a product of some kind of feedback control being operated by the long term memory store. Consider the number of items logarithmically found in 1.5 bits. There are three items in 1.5 bits of REAL information. The non-isolated, average value of REAL decreases when a memoryless condition is determined for a set of cognitive behaviors. The ay intercept regression values also decrease when treated for memoryless conditions. Now compare the strength of dependence between messages with REAL information measures in Appendix VIII (experiment 13). Notice that the REAL value at memoryless conditions for <u>total</u> (1.0584 bits), anatomy topic (1.0647 bits), seeds topic (1.1652 bits), and the laboratory setting (1.0367 bits). These are the approximate values of the REAL information flowing when there is no dependence between messages.

According to Shannon (1), there is a channel capacity which is partly controlled by equivocation (which when used positively is called error correction information). The equivocation used for an input, H(x), into a channel can be plotted. This graphing operation enables determining the attainable region for the error capacity of a channel. C. Shannon hypothesized that capacity would have a slope of 1.0, or one bit of equivocation per bit of H(x) input. The trigram codes for the 30 science classroom dialogues were found to have a plot slope of 1.03. This finding, again, enables drawing an inference because the H(x) is approximately the sum of $H_y(x)$ and REAL (if it is computed as REAL IN x).

These data for the REAL measure, in different experiments, show that the useful information decreases to about one bit when there is no dependence between consecutiv messages, as the memoryless condition is obtained in the memory model. The error correcting factor increases to a maximum value in the memoryless condition, becoming analogous to an errorful capacity channel, and the area of attainable input rates becomes constricted. If there is no error correction information, all of the input H(x), consists only of useful information (REAL-SS). So as the strength of dependence is suppressed to zero, the REAL-SS value becomes 1.0584 bits (see Appendix VI). As $H_y(x)$ is suppressed (see Appendix VI) the H(x) input is 1.3690 bits and the b_{xy} slope of the unit increase is 0.2687 bit H(x) for each increase of $H_y(x)$-SS bit. The b_{xy} slope is operating at 1.1046 $H_y(x)$-SS bit for each H(x) input in the memoryless condition. Thus some kind of feedback system operates wherein, as a memoryless condition ensues, the LTM store has an operator which serves as a governor, or a comparator such as suggested by Sternberg (29). The operator feeds back on the input which, when the score is zero, has a value of 1.4392 bit. This is the H(x) input if there is no error correction factor to serve as a control on the retrieval of the next message. The $H_y(x)$, however, has maximized to 2.8656 bits. When there is no dependence between messages, the activation of the error corrector in the LTM is probably related to the information residue found in the REAL measure; which was stored to represent shared messages. This is 1.0584 bits at zero dependence. The "controller" for this is that no error correction would be 1.3690 bits of input. So the phase space of 1.1046 bits approximates the 1.0584 residue for the two preceding (shared) messages. This useful information was stored after cognition for them had occurred. The intellect for the treatment of investigations operates at an upper limit of 1.5814 bits of REAL-SS. The REAL-SS is negatively correlated with the strength of dependence. The $H_y(x)$SS is positively correlated with the achievement score. The strength of dependence is negatively correlated (not significant, but not very close to a zero correlation) to achievement score. So the criteria are met for a negative and positive oscillating feedback system. This would then be a deviation-counteracting class system. That is the kind of system which would be logically expected to correlate the interactions of the external world input and the intellect with the memory processor units of a memory model. This relationship is now under study. We could expect that a deviation-amplifying counteracting feedback system would operate in a "learning" kind of experience.

The reader may still be curious as to why the b_{yx} slopes of the regression analyses for the relationship of the MAT to information measures in experiments six through eleven are so similar. The interpretation could be that an increase of one point in the MAT score is "accompanied" by a small increase or decrease (of 0.0006 to 0.0384 bits) in the value of an information measure. The consistency is seen in the CODE slopes in "average" tasks and in the average recall task (Appendix VII). Both entries show a value increase of 0.0203 bit CODE for each MAT score point increase.

It has been mentioned several times that the error correction information measure is a comparator mechanism. (Sternberg (29) hypothesized that information retrieval is operated by two pathways. One is by using a comparator and the other is through the use of a scanner. We could infer that the scanner is the CODE signal. We have also mentioned that the useful information (REAL) is eventually constructed partly through the events in some kind of feedback system.

The idea of there being a feedback system was pursued through an analysis as to whether or not some kind of negative or positive feedback occurred for "start-up" and "rate-levels" in the control of information flow by the intellect. This approach involves the ay coefficient as the information flowing when there is no intellect control. The rate of increase or decrease of the information flow is for each unit increase or decrease in the MAT score, which is the byx slope value shown in Appendix VII.

A positive feedback system is one in which there is a deviation-amplifying counteracting relationship between two variables, or between two information processing components in the memory model. We could expect that some aspect of a recall task information process in a memory would involve a positive feedback loop. It can be assumed that the process involves an interaction of retrieved LTM information, and the output would be displayed in the environment. The information would be expected to be subsequently perceived by the human who originated it. That perception would then serve as some kind of learning experience because, as it is again input, it would increase the level of structural comprehension the human would have of his or her control over the responses he or she had used in constructing an external world body of knowledge. In other words, a person doing a written statement would output a message. Then he or she would,through a visual perception or by subvocalizing, input what was the nature of that output. This "connection" of the output and input flow can be expected to produce a deviation-amplifying flow of information, and could be regarded as a pseudo-learning structuralization. This kind of reasoning enabled us to use a positive feedback system rationale for the search of a feedback system.

The basic positive feedback equation is: $y/x = K_1/1-K_1 K_2$. The y symbol represents an output and the x is the input (see Milsum, 42). The K factors represent gains. A negative feedback equation differs by a change of the denominator minus to a plus sign. We hypothesized that the K factors would be the byx slopes because they represent negative or positive rate changes. The input would be an ay coefficient and would mean there was a "start-up" of the "intellect" influence or control. The y output would need to be an expressed slope, which would indicate the rate and direction of the action brought about by feedback pathway influences.

The feedback equation elements are listed in Figure II. Figure II also contains a diagram of the loops and pathways for feedback between information processes in the memory model. The results of the three feedback equations were not found to differ by more than three percent from the slope values of the regression analyses (Appendix VII) done in comparing the information measures with the MAT scores. These data treatment results are of the previously described average recall tasks.

Three information feedback pathway systems were found to operate in the memory. The "start-up" of the intellect (ay in Appendix VII) initiated K_1, K_2 loop gains (byx values) which influenced the rate and direction of changes of information processing. Two of the "start-up" inputs resulted in change influences in different areas of the memory than where the system began. The memoryful code ratio signal resulted in a positive feedback influence in the memoryless REAL information gain. This is seen in Figure II as the "21" series pathway. The LTM REAL component in turn initiated a pathway which influenced the CODE signal in the STM. The flow differed in that the K_L was alternated; the former pathway K_1 being an error correction "decrease" change. The latter pathway had the K_1 gain as the CODE signal. The effect was a negative feedback on the CODE signal.

The third loop pathway was initiated by the memoryful REAL information ratio and remained in the STM by means of loop actions of the error correction factor and the CODE signal. The outcome was a negative feedback influence on the rate of change in the ratio of the REAL information being formed in the STM.

The reader may find it difficult to understand how a negative feedback output on a positive slope rate of change can occur. The explanation for this effect is found in the nature of feedback systems. The diagram in Figure II represents a general system which operates in an interacting fashion, wherein systems of pathways have influences upon the general outcome of a process (43). Milsum (42) explains this phenomenon as a "stability" effect. The reader is referred to Maruyama (43) for a simplified explanation. Briefly, odd number of minus loop influences produces a negative feedback effect, an even number of influences results in a positive effect. The loop influences in Figure II are identified by plus and minus signs in parentheses. A double parenthesis identifys the slope gain factor of the initiator or "start-up" actions (ay in Appendix VII). Analyze the pathways of a system for obtaining the output change. The REAL-SS feedback output influence sign corresponds to that found for the slope change in the regression analysis (Appendix VII). The other two pathways traversed through the interaction of the K_1,K_2 loops twice. For example an STM initiated % REAL goes through an $H_y(x)$ to CODE loop twice and the net effect is the consequence of the number two minus influences which "cancel each other and become positive in effect" (43).

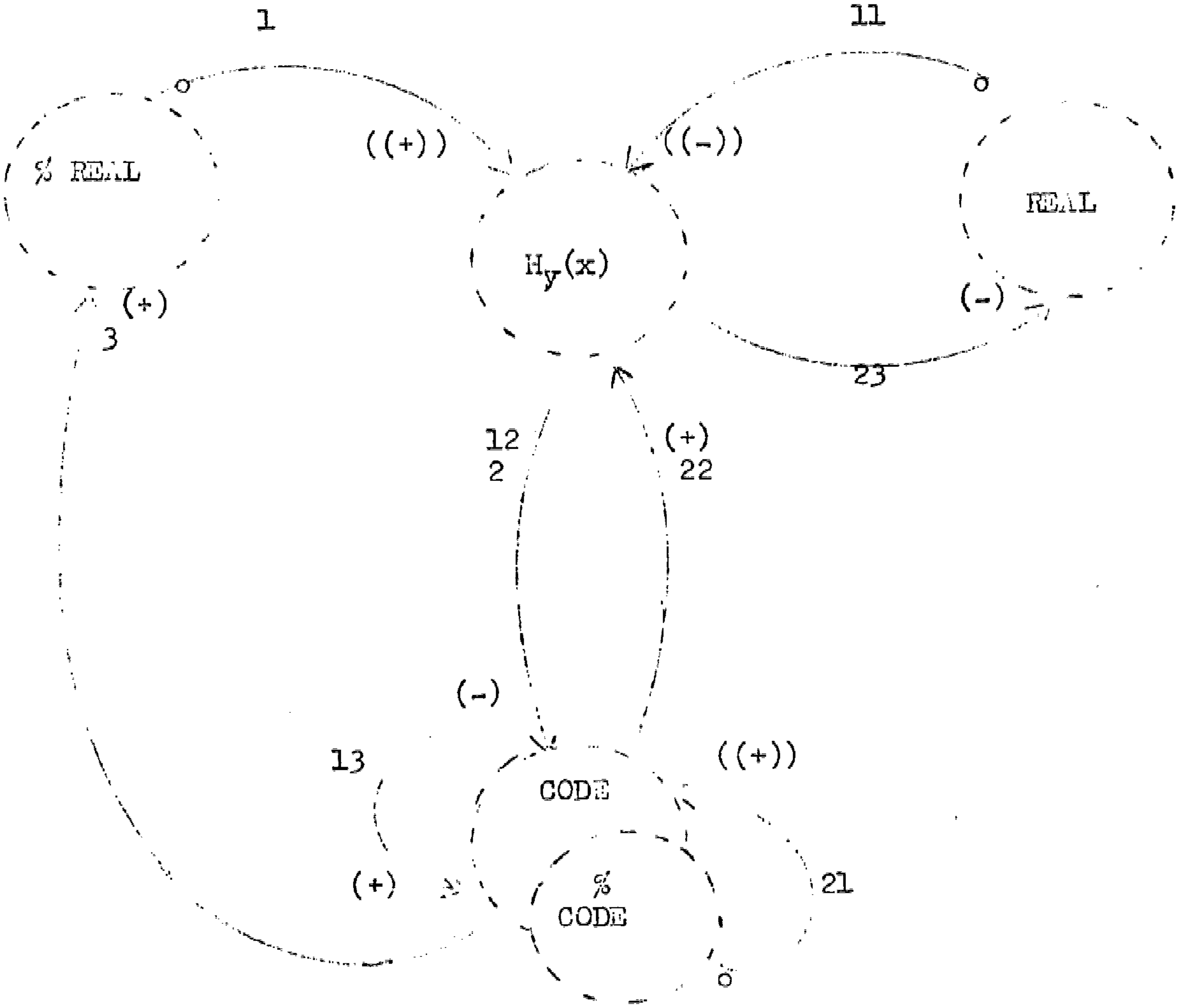
Positive feedback systems have deviation-amplifying causal relationships. The direction of change of the system is toward instability. A negative feedback system is deviation-counteracting and tends to go to an oscillating condition. The positive feedback systems, have as their end products, the gain ratios of the REAL information and CODE signal in the STM. So, the net affect is to amplify the gain ratios of the outputs. The sources of the start-up" for these component actions initiate from the two memory stores. A possible conclusion is that we have found the previously claimed "transfer" relationship between the memoryful and memoryless LTM information measures and this feedback partly explains how some tasks are processed more extensively in the STM than the LTM. The deviation-counteracting system which effects the slope gain of the REAL-SS is quite different from these two systems. The initiator is the CODE ratio in the STM. In this case, then, the influence is to "stabilize " the REAL information rate of information retrieval when the intellect control becomes active. This loop system may easily not do any more than traverse the "start-up" of the REAL of the LTM to again operate through the loops of the feedback system which controls the rate of gain for the formation of a CODE signal in the STM. In finding 4 we postulated the role of the error-correction factor to be one of "deciding" the CODE process in the STM. This feedback system seems to make that claim more probable.

We are continuing the study of the probability of there being feedback systems in the memory. To date, there are several other indications that they have been identified. Additional evidence is being sought from results recently obtained in three new experiments.

FIGURE II

Feedback Loops for Information Pathways

Initiator	Feedback Action	First Loop Gain	Second Loop Gain	Outcome Gain
ay, % REAL-M^1	positive	$H_y(x)$-M^1	CODE	% REAL-M^1
ay, REAL-SS	positive	$H_y(x)$-M^1	CODE	CODE
ay, % CODE	negative	CODE	$H_y(x)$-M^1	REAL-SS



Conclusions:

This paper reports a new memory model, which describes the flow of information in the processing of cognitive tasks by humans. Information Theory, developed by C. Shannon (1), is used for quantifying the flow of information. Additional theorems were developed for improving the application of Information Theory to the model. The rationale for the information theoretic approach was that it enabled a quantitative description for human behavior. The initial information values describe the observed behaviors of humans who are doing a task in the external environment. These information measures are then treated by various theoretic algorithms which enable the identification of information values for various known memory areas and processors of cognitive tasks. Eighteen primary and secondary information measures are used for the identifications.

Twenty-two experiments and studies were conducted in the development of the memory model. Thirteen of them were reported in this description of the model. External and internal criterion tests were done for determining how its' components and processes functioned internally and how they related to external criteria. The extensive testing of the model was facilitated by the use of the common measure value called "bit". The qualities of the model were defined in order to test the development criteria as being:1) the basis of how "real world" facts were used to rationally "explain" why information values existed, 2) how model components interacted to "explain" basis number one, 3) how humans differed in behavior in terms of information measure values, 4) how the information values "explained" psychological studies on behavior, maturation, and learning, 5) the extent to which achievement and intelligence indicators were "related" to information measure values, and 6) how the foregoing could be used algorithmically to "discover" the nature of additional processes and components in the model.

The research approach taken in the development of the model was based on the following aspects: 1) information measures were mathematically tested for theoretical interpretations, 2) data of studies were treated for identifying possible applicative meanings of measures, 3) statistical testing was done for determining the possible significances of those measures, 4) new experiments were designed with a priori outcomes set to the expected model interpretations, 5) collected data was tested for sample interpretations in terms of cognitive actions, 6) new findings of model functions were then retroactively tested for identities in data of previously treated experiments and which contained corresponding meanings, 7) the measures used in the number of experiments which were done for criterion tests were studied for developing indicators of general cognitive processes, differences in cognition of task processing and of human behavior in learning environments. The approach may not seem to be "clean" but the nature of the model "grew" in complexity in a way which defied discrete experimental practices. The model developed in a fashion which demanded many new strategies for the findings, and these often defied a coordinated design because of the many ways in which findings needed to be tested and studied. The author recognizes, and has previously stated, that the memory model is not completed and will require some refinements. The development of new components is not expected, because the findings and sub-findings presented herein indicate new criteria would be "masked" by algorithmic systems of existing component interactions.

The memory model is quite unique with respect to other models. This is a major conclusion (001) as this model quantifies the qualities of memory processes, whereas others have not. The philosophy of the model is exhaustive in its' relations to humans, human behaviors in cognitive tasks, cognition, and cognitive quality. The techniques for coding behaviors were selectively chosen for compatibilities to behaviors and were often used in multiple treatments of the same observed behaviors.

The memory does have an STM and an LTM and these model "areas" can be interprete information theoretically as being memoryful and memoryless (002). There is considerable evidence that these "areas" play particular roles in the processing of types of cognitive tasks (003). The nature of human "behaviors" in cognitive task processing was partly defined and certain information measures enable explanations of the roles of the STM and LTM in cognitive processes (004). It is quite probabl. that structures of these "areas" are in some way involved in mental maturations (005). Piagetian type of studies are now in progress to clarify information measure relation ships.

The STM "area" of the memory does utilize the "chunking" process postulated by G. A. Miller (8). The CODE, CODE signal ratio, $H_y(x)$, and LTM memoryful information measures were "detected" as being a part of that process (006). The LTM "area" is a storage area of informational content but does not seem to be greatly involved with attentional behavior kinds of processes (007).

Various information measures were found to be "correspondent" to memory components of models proposed by others (008). The CODE and signal ratio, is that process most recently suggested by Atkinson and Shiffrin (34) and may be related to the scanner process proposed by Sternberg (29). The Sternberg "comparator "is probably the error correction factor; which is the equivocation information measure.

The useful information flowing in the memory is what others identify as that information retrieved from the LTM or developed by processes in the STM (009). The information, called REAL, is also of another type which "relates" the "old" information to the information being "formed" for a "new" behavior action (010). The LTM information measure is the informational "kernel" and is found through LTM or STM output processes (011).

Error correction (($H_y(x)$) is called a factor because it operates as a "controller" in the model (012). It is an information measure which has an interand-intra geographic "area" flow (013). The factor seems to function in decision-making processes (014). The formation of a signal message or the "decaying" of a message in the STM "area" is probably controlled by the factor. It is also related to the recognition of incoming memory messages and to the levels and kinds of REAL information measure roles (015).

The memory is a noisy channel which is errorful (016). Several information measures of "noise" (shared, in x, and in y), were found to be meaningful in the operating (cognition) model. The levels of noise in a flow process is related to the input message and is generally indicative of the kind of cognitive task being processed in the memory stores (017). It is also a theoretic proof for kinds of tasks selectively treated in the LTM and the STM (018) This is seen in how high is the noise level in the memoryless condition, the degree to which noise of input and output is balanced, and the extent of the difference between the noise levels of the LTM and STM.

The LTM measure was previously mentioned as being the "kernel" informational content of the useful information (REAL) in the message being formed for an output behavior. It is an indicator of the kinds of tasks being processed (019). The LTM measure is equal to the REAL information measure in the LTM, or memoryless condition. This is the proof for it being the "kernel" and that the LTM is the isolated, "message-independent", long term memory store often hypothesized by theoreticians and researchers of the human memory (020).

The group of followers of D. Ausubel (44) use the term subsumer as some kind of memory organization unit. It is quite likely that the LTM, memoryless LTM, REAL, information measure is that "subsumer" unit (021).

Consecutive messages are stored in the STM until they are processed. The CODE measure is the signal used for searching the LTM "file" for retrieving a "new" message or for the previously mentioned STM "chunking" process (022). It is also a measurement of the strength of dependence between message sequences stored in the STM (023). The strength of dependence between messages served as still another proof that an LTM or memoryless condition exists in the human memory (024). Data was treated on a computer to determine the Markovian steady state. Subsequently, the author derived a proof of the CODE role in determining the steady state and an operational definition for determining steady state for message processing relationships (025). There is some evidence that the strength of dependence factor is related to perception, attentional behavior, and to the kinds, and degrees of success obtained in cognitive tasks being cognitively processed (026).

Humans engaged in problem solving tasks can be identified for their solving characteristics; the information measures and the nature of the flow of information in the memory (027). Elementary and secondary school age children are distinguishable by the values of LTM, strength of dependence, REAL (LTM) and noise factor information measures (028). Felen and Moser recently supported this conclusion (45.) The data studied in other experiments or problem solving have also established the validity of the conclusion. There is some evidence that these information measures also indicate levels of success in training humans to solve problems (029).

The previously mentioned information measures are related to and can be used as indicators of, the recall and recognition types of cognitive tasks (030). Recognition types of tasks are processed to a greater extent in the STM than they are in the LTM (031). Recall tasks are more extensively related to the flow pathways of the LTM than the STM (032). These memory "area" roles in the processing of task information will be discussed again in this section (see below).

It was found that, using gram code systems and term analysis, verbal messages flowing into the human memory are processed in "phase spaces" (033). The structure is perceived on a time level of flow and is geometrically "accretionized". The -product is an embedding phenomenon (034). This kind of treatment also isolated attentional behavior (035). The attentional behavior of humans is directly related to the STM and is not largely a role for the LTM memory components (036). The information measure values which isolated attentional behavior tend to indicate a means for identifying mental maturation levels of humans (037). The final conclusion, reached in structural analyses, is that the model component can be used to define "semantic" aspects of dialogues and monologues (038).

The memory model is directly related to "real world" activities. Several experiments showed that the information measure values were sensitive to the environmental settings in which humans process behavioral actions and to the kind and degree of perceptual information existing in the external world (039).

The human intellect and its role in processing cognitive tasks is related to the amounts and kinds of memory components which "flow" in the processing of information (040). This is a quite strong and revolutionary conclusion. A classic study was done of six different experiments with the same adult individuals. The analysis technique used in those experiments was also used to analyze groups of children engaging in the solving of science investigations. The design approaches and "variables" were manipulated to isolate and identify human behaviors, environment settings, content of tasks, kinds of tasks, person qualities, and transmission modalities. This was done to establish strong levels of relationships between external and internal criterion measures. Eleven information measures were found to be significantly related to MAT scores of adults or to achievement scores of adolescent children. The relatedness tests of regression are not completed for all of the 18 information measures. The 11 measures which were found to be related are $H(x)$, $H_x(y)$ R.E., CODE, CODE ratio, REAL, $H(x,y)$, NOISE (in x), $H(y)$, and $H_y(x)$ of the memoryful condition; LTM and $H_y(x)$ of the memoryless condition (041).

Information measures were found to be related to the intelligence of humans in recall task processing, but fewer measures were related in the kinds of problem tasks which were being processed by the humans. Six information measures for both kinds of tasks were found to be significantly correlated with MAT scores and achievement scores. Tests of coefficients of correlation with MAT, indicated that some information measures processed in recall and problem solving tasks, were of a common population. This characteristic is under study.

The discovery of the memory model being related to external criteria measurements was considered a major proof of the validity of the model (042). It was concluded the information theoretic components were in some way "reading" the same memory processes or human behaviors which were also reflected in the intelligence and, the cognitive processing efficiency of humans. The correspondence meanings of these two types of measurements of human cognitive activities is being explored. The tentative conclusion is that certain information processing components in the model are probably those memory processes more directly related to the intellect (043). The reader is cautioned to draw no greater inferences than that one herein tentatively advanced.

The regression analyses of model components and MAT scores enabled a means for studying how processes of information flow interacted in the memory. Data from "average" recall tasks (see finding six) were treated for the probability that the interactions were of some basic feedback type. The treatment rationale was to assume a zero intellect influence had initial kick qualities, and gain" loops existed for change rates in the processing of information. The feedback systems were found to operate between signal formation (CODE), error correction information, and the REAL information factor. The causal relationship is believed to be for one memory process to influence another process; through influences of two other processes (044). Three feedback systems of positive and negative feedback kinds were found to be of a general feedback system (045). The loops of information flow were found to relate STM processes with LTM processes (045). The direction and control of information flow found in the feedback systems is additional evidence for the proposed structure of the memory model (046).

The foregoing evidence for feedback systems in the memory is supported by other findings. Error correction data of informational content from one of the experiments confirmed and demonstrated C. Shannon's (1) theorem for error capacities in channels. He postulated the ideal limit would approximate one bit of correction information for each input bit. We found that many error correction measures are processing close to that limit in the human memory. The dialogue messages in a study of 30 science classroom lessons obtained a channel error capacity slope of 1.03 in the memoryful condition (046).

The afore-described findings and the conclusions drawn from them are regarded as a quite strong argument that the memory model lists, defines, and describes cognitive processing in human minds. Its' quantification of the quality of memory processes through the flow of information occurring in those processes is a subtlety which can be easily overlooked. The values of the information flow for kinds of behavior messages are of definable ranges and limits. The large number of studies and experiments done in the memory model project substantiated this claim (see Appendices three through eight). A catalog of these information flow values is in preparation and it may have considerable potential for identifying, assessing, and understanding the meanings of task processing in learning environments.

The memory model is being reported at this time, even though it is not complete. The author decided to report it so other researchers may study it, communicate queries and criticisms, and "join" the memory model project group in further research. We believe that, even at this stage of completion, the model has universal applications for describing human behavior and will ultimately be a revolutionary means for interpreting when and how learning occurs in educational practices.

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APPENDIX I
Description of Experiments

(1) Information processed in verbal classroom lessons.

Thirty junior high school science lessons were selected to obtain a wide range of percent of teacher talk (26 to 98 percent). The taped dialogues were interaction coded using a Parakh-Modified Category system. An average of 476 messages per lesson were coded, at an average of four seconds per message. The dialogues were then treated to determine the amount of information processed by the human participants.

(2) Information processed in non-verbal problem-solving.

Twenty-four schools in Western Pennsylvania participated in the study. Children were randomly selected from each grade level from one through twelve with each grade represented in two schools. A total of 240 pupils were involved in the study. Subjects were given the parallel electric circuit problem to solve; wherein they were to complete a circuit consisting of a single dry cell, five wires, two light bulbs with receptacles, and a single-throw switch. The completed circuit was to be such that both bulbs lit and when one bulb was unscrewed the other bulb remained lit. The manipulative actions of the humans were systematically recorded. Information measures were then determined for each group of children at each grade level.

(3) Information processed in verbal group problem-solving (abstract), high school level.

Five female biology students were randomly selected for the experiment. They were given a written problem statement to solve. The problem was that two children left Cleveland, Ohio and went on a vacation to Denver, Colorado. There, they became ill and on returning to Cleveland, were again well. The subjects were asked to enumerate the possible causes of the illness, and then to "discuss" each cause separately. The subjects "identified" the causes as being pollution, plants, homesickness,and altitude. The audio-taped dialogue was term analyzed and then was analyzed using the Parakh-modified (23) interaction category system (63 different codes). Each topic block of codes (term or category) was placed in a matrix and treated for information theoretic measures.

(4) Information processed in interpreting concrete science objects by "concrete" and "formal" operational children.

Children aged 6 through 12 years participated in 12 experiences with science phenomena of thermal expansion, the radiometer, magneto-generator and chemical solutions. Each experience was conducted by a different science teacher, on a one-to-one basis. The 20 minute "interviews" were audio-taped and analyzed using modified Parakh interaction analysis category system (63 code labels). Each dialogue tally was sequentially entered into a matrix and treated for information theoretic values.

(5) Information processed in a chained recall task, number one.

Thirteen graduate science education (secondary science) students participated in the experiment. Three of the subjects listened to a five minute statement on steady state conditions for information processing. The statement had been originally designed for a variety of 30 different terms. It was verbally processed for a maximum of H (X) relative entropy (91.95%) and to have a problem-solving level of error correction information. Two subjects were then selected to serve as initiators of a chain of information transmission. The third subject was told to "forget" about participating in the experience. The two chain initiators were asked to present a monologue of what they had heard to another subject. These subjects were given five minutes to verbalize what they had heard. In this manner, the chain links were processed through a length of five subjects, and the last one "spoke" to a tape-recorder. On the completion of the two parallel-operating chains of 35 minutes in length, the third source receiving subject was asked to initiate a chain. That chain had a length of three links. The monologues of the subjects were each term-analyzed and these were placed in a matrix. Then each matrix was treated for information values. The subjects of the recall experiment were then given the Hunt Conceptual Level Test. The test responses were treated using digram code labels from a modified Parakh Category System. These tallies were also treated for information theoretic values.

(6 and 7) Information processed in a chained and delayed recall task, number two.

Fifteen graduate science education (elementary and secondary science) students participated in the experiment. They were selected on the basis of previous findings of their having processed information in other experiments. Seven of the subjects listened to a specially designed verbal statement. This statement was on an audio tape and had been used in a similar experiment four months ago. The source statement is described in Experiment Number Five. Two of the source receivers (subjects) were then selected to initiate a recall chain(6). A chain is the sequential "passing" of information from one human to another (described in the preceding experiment description). When the chain was terminated, each of the fifteen subjects was asked to write a statement of what they had heard. They were given 18 minutes to complete this recall task(7). Each statement was term-analyzed and placed in a matrix. Then information theoretic values were calculated for each subjects' output in the chain recall and delayed recall tasks. It should be noted that the delay in recall involved 30 minutes for five subjects, 25 minutes for two subjects, and a range of 20 minutes to zero minutes for each of two remaining students.

(8) Information processed in an abstract problem-solving task, college level. Each of 18 graduate science education students were asked to solve an abstract problem which was on a typed page. The problem involved an incestuous relationship between nine people who had 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 224 words in length. The term location and wording sequences of the statement were specially constructed to establish a source which was a 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 (87 terms and a variety of 26). Each subjects' output was placed in a matrix and treated for information theoretic measures.

(9) Information processed in a recall task (abstract), college level, number one.

A 600 word passage was read to a group of 15 graduate science education students (elementary and secondary science). They then immediately spent 18 minutes writing what they had heard (based on a time study ratio of writing and speaking rates; for hearing a five minute passage). The source of the content was abstracted to 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 subjects' tally of terms (sequential) were placed in a matrix and treated for information theoretic values.

(10) Information processed in a recall task (abstract), college level, number two.

Nineteen graduate science education students (elementary and secondary science) were asked to write about "What is science learning". They were given 15 minutes to write the statement. Each statement was term analyzed and these were placed in a matrix for determining information theoretic values.

(11) Information processed in a recognition sorting task, college level.

Seventeen graduate science education students (elementary and secondary science) participated in the experiment. They were shown an overhead projection of fifteen 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 elements (by number labels) of sets of figures (or colors; with a minimum of three elements per set. The sequence of elements and sets were 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 subjects' total entries (match plus non-match) were again placed in matrices for the treatment by information theoretic procedures.

(12) Information processed in non-verbal problem-solving, with training (electric circuit, college level).

Fifty-seven students enrolled in a general education college science course at Indiana University of Pennsylvania participated in the study. The students were randomly assigned to attempting to solve two tasks. These were the three-way electric circuit and parallel circuit problems. Then, depending on success or failure in the problem, they were given a ten-minute training in the electric circuit problem. Following the training, they were again given the three-way electric problem. The sequences of connections made in each of the "solving" procedures were entered into a matrix. These matrices were then treated for information theoretic measures.

(13) Information processed in laboratory and non-laboratory group problem-solving, seventh grade.

Eighty children (in two local schools) were randomly assigned to twenty groups. The children were enrolled in a science course using the text entitled The Interaction of Man and the Biosphere (Rand-McNally). The groups were, randomly, assigned to complete investigations on the anatomy of the digestive system and location of food in a germinating seed. The groups were then randomly assigned to work in a laboratory setting or with no aids other than the textbook description of the investigation. The laboratory and non-laboratory sets of groups engaged in the experiment at the same time. Both setting groups were audio-taped and those were term-analyzed. The children also answered the text questions for the investigation. These were scored by three teachers of the course. The matrices of the dialogues (terms) were treated on a computer (GE) for steady-state levels of independence.

APPENDIX II

Information Theoretic Measures

1. Actual Information: $H(x)$ The entropy or the information of the source of messages: $H(x) = - \sum p \log_2 p + \ldots$

2. Bit: A contraction of the 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; when in a noisy channel is influenced by equivocation.

4. Code: The filtering-out process· According to the Moser Model, the brain will process the incoming message as a signal for information development and retrieval.

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, or for forming a short term memory oriented message.

6. Conditional Information or Dependent Information: The uncertainty in the received signals if the message sent be known. Expressed as the uncertainty of y, knowing x; $H_x(y) = p_1 - \sum p \log_2 p + \ldots$

7. Equivocation: The uncertainty as to what symbols were transmitted when the received symbols are known: a form of noise $(H_y(x))$; has an error correction function in a transmission channel.

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 cells used in a matrix, assuming all items are equally probable in having occurred.

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

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.

Appendix II
Continued

14. Noise in Input: The amount of spurious information in the input messages in a transmission channel or memory model.

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. If an STM oriented message is formed, it is a "chunk" made up of CODE plus LTM-M^1.

16. Percent Real: The portion of a transmission channel which is useful;constitutes the kernel for an output message.

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

18. Conditional Relative Entropy: $H_x(y)$ R.E.: The amount of information in the second message with respect to the total possible information, when the first message is known.

19. Shared Information: The amount of information shared by consecutive x and y messages in a transmission channel. Expressed as 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 degree of dependence between x and y events in a Markovian Chain. In the Moser Model, it is the amount of code remaining at steady state.

APPENDIX III

Code Signal Ratios in Eleven Experiments*

	CODE[1]
Exp. 1. Classroom Dialogues	
Monogram	.8427
Less than 70% teacher talk	.8384
More than 70% teacher talk	.9295
Digram	.7412
Less than 70% teacher talk	.7124
More than 70% teacher talk	.7727
Trigram	.6060
Less than 70% teacher talk	.5970
More than 70% teacher talk	.6149
Exp. 2. Electric Circuit Problem	
Success	.3583
grades 1-6	.4455
grades 7-12	.2835
Failure	.2345
grades 1-6	.2184
grades 7-12	.2522
Exp. 4. Interpretation of Phenomena	
Monogram	
6 Yrs. old	.0598
8-10 Yrs.	.0717
12 Yrs.	.0235
6 and 12 Yrs. old	.0416
Digram	
6 Yrs. old	.1002
8-10 Yrs.	.1884
12 Yrs.	.0388
6 and 12 Yrs. old	.0945
Trigram	
6 Yrs. old	.2994
8-10 Yrs.	.3639
12 Yrs.	.3162
6 and 12 Yrs. old	.3078
Exp. 6-11:	
Average Recall	.7172
Average Problem Solving	.5947

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* See Appendix I for descriptions.

[1] To be read as bit per input (H(x)) information.

Appendix III
Continued

Recall:	CODE[1]
Exp. 7. Delayed Recall	.6939
Exp. 9. Recall of Passage	.6956
Exp. 10. Free Recall	.7526
Problem Solving:	
Exp. 6 Chained Recall	.5954
Exp. 8 Abstract Problem	.5860
Exp. 11 Classification Sorting	.6036
Exp. 12 Non-verbal Problem Solving, with and without training electric circuits:	
a) Pre: 3-Way: Success	.4790
b) Pre: 3-Way: Failure	.2033
Post: 3-Way: Success	.3866
c) Pre: Parallel: Success	.1858
Pre: 3-Way: Failure	.1151
Post: 3-Way: Failure	.1520
d) Pre: Parallel: Failure	.1170
Pre: 3-Way: Failure	.1541
Post: 3-Way: Failure	.1694
Exp. 13 Laboratory and Non-laboratory Investigations	
Total	.5007
Non-laboratory	.4850
Laboratory	.5165
Anatomy Topic	.5525
Seeds Topic	.4490

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* See Appendix I for descriptions.

[1] To be read as bit per input bit (H(x)) information.

APPENDIX IV

Error Correction Information Factors Processed in Tasks and Amounts of LTM Information in Memoryful and Memoryless Conditions

Experiment Number[1]	Input, treated by Error Correction Information[2]	Proportion of LTM IN:[3]		LTM in Memoryless Level; not in M^1 (%)
		Memoryful	Memoryless	
(1) Classroom dialogues				
a) Monogram:				
Less than 52% T-Talk	.1774	.5717	.4283	0
b) Digram:	.0943	.4879	.5121	.0471
c) Trigram	.0459	.3715	.6285	.4073
(MONO) Less than 52% T-talk	.3069	.6849	.3151	0
52-70%	.5168	.8346	.1654	0
70-80%	.5211	.5191	.4809	0
80-90%	.2053	.4910	.5090	.0354
90-99%	.8535	.5004	.4996	0
(DI) Less than 52% T-talk	.2263	.4917	.5083	.0327
52-70%	.1769	.6016	.3984	0
70-80%	.4297	.5367	.4633	0
80-90%	.2668	.4662	.5338	.1269
90-99%	.6565	.4510	.5490	.1787
(TRI) Less than 52% T-talk	.2239	.3582	.6418	.4420
52-70%	.1885	.3602	.6398	.4372
70-80%	.1848	.3616	.6384	.4336
80-90%	.1281	.3877	.6123	.3670
90-99%	.4751	.3878	.6122	.3666

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(1) Experiment descriptions are found in Appendix I

(2) To be read as entry of error correction information (bit) per input (H(X)) bit of information.

(3) Interpreted as percent of total of information in original and independent levels.

Appendix IV
Continued

Experiment Number[1]	Input, treated by Error Correction Information[2]	Proportion of LTM IN:[3] Memoryful	Memoryless	LTM in Memoryless Level; not in M[1] (%)
(2) Electric Circuit Problem				
Success:	.5675	.2951	.7049	.5814
Grades 1-6	.5076	.1403	.8597	.7723
Grades 7-12	.6257	.4223	.5777	.2426
Failure:	.6807	.5000	.5000	0
Grades 1-6	.7823	.5649	.4351	0
Grades 7-12	.5698	.4453	.5547	.1973
(3) Verbal prob.solving (trigram)				
Block one (causes)	.3917	.2376	.7624	.6883
plants	.4081	.1086	.8914	.8781
pollution	.4623	.1096	.8902	.8767
homesickness	.2082	.1858	.8142	.7719
altitude	.3184	.1667	.8333	.8289
total	.4523	.2897	.7103	.5923
(3) Verbal prob.solving (term)				
Block one (causes)	.6864	.4763	.5237	.0905
plants	.4978	.1332	.8668	.8464
pollution	.1405	.4085	.5915	.3094
homesickness	.1965	.2368	.7632	.6898
altitude	.3936	.3089	.6911	.5531

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(1) Experiment descriptions are found in Appendix I
(2) To be read as entry of error correction information (bit) per input (H(X)) bit of information.
(3) Interpreted as percent of total of information in original and independent levels.

Appendix IV
Continued

Experiment Number[1]	Input, treated by Error Correction Information[2]	Proportion of LTM IN:[3]		LTM in Memoryless Level; not in M^1 (%)
		Memoryful	Memoryless	
(4) Verbal prob.solving (Piagetian):				
Monogram:				
6 Yr.	.7120	.5759	.4241	0
8 and 10 Yr.	.5862	.5625	.4375	0
12 Yr.	.7802	.5322	.4678	0
6 and 12 Yr.	.7461	.5550	.4450	0
Digram:				
6 Yr.	.5720	.4787	.5213	.0820
8 and 10 Yr.	.2209	.4743	.5257	.0978
12 Yr.	.5760	.3948	.6052	.3479
6 and 12 Yr.	.5740	.4328	.5672	.2372
Trigram:				
6 Yr.	.5920	.2369	.7631	.6896
8 and 10 Yr.	.1038	.3262	.6738	.5159
12 Yr.	.4628	.2700	.7300	.6301
6 and 12 Yr.	.5274	.2572	.7428	.6538
(5) Chained Recall, number one				
a) Recall	.2826	.1192	.8088	.7637
b) Hunt Test	.4695	.3486	.6514	.4648
(6 and 7) Chained and delayed recall				
6) chain	.3541	.1246	.8754	.8604
7) delayed	.2332	.0984	.9016	.8986
(5,6,7) SOURCE	.3466	.0482	.9518	.9493

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(1) Experiment descriptions are found in Appendix I
(2) To be read as entry of error correction information (bit) per input (H(X)) bit of information.
(3) Interpreted as percent of total of information in original and independent levels.

Appendix IV
Continued

Experiment Number[1]	Input, treated by Error Correction Information[2]	Proportion of LTM IN:[3] Memoryful	Proportion of LTM IN:[3] Memoryless	LTM in Memoryless Level; not in M^1 (%)
(8) Abstract prob.solving				
a) actual	.3889	.0880	.9120	.8985
b) SOURCE	.3968	.1141	.8859	.8712
(9) Abstract recall, one (Brain)				
a) actual	.2658	.0476	.9524	.9038
b) SOURCE	.2979	.0164	.9836	.9836
(10) Abstract recall, two (Sci.)	.2510	.0149	.9851	1.0167
(11) Recognition sorting	.3821	.4530	.5470	.1022
(12) Non-Verbal prob.solving, with or without training (electric circuit)				
a) Pre: 3-way: Success	.4596	.6494	.3506	
b) Pre: 3-way: Failure	.7303	.6207	.3793	
Post: 3-way: Success	.4821	.8468	.1532	
c) Pre: Parallel: Success	.7268	.6675	.3325	
Pre: 3-way: Failure	.8200	.4286	.5714	
Post: 3-way:Failure	.7735	.6270	.3730	
d) Pre: Parallel: Failure	.8031	.8089	.1911	
Pre: 3-way Failure	.7645	.7283	.2717	
Post: 3-way: Failure	.7305	.7087	.2913	

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(1) Experiment descriptions are found in Appendix I
(2) To be read as entry of error correction information (bit) per input (H(X)) bit of information.
(3) Interpreted as percent of total of information in original and independent levels.

Appendix IV
Continued

Experiment Number[1]	Input, treated by Error Correction Information[2]	Proportion of LTM IN:[3] Memoryful	Memoryless	LTM in Memoryless Level; not in M^1 (%)
(13) Laboratory and Non-laboratory task processing:				
a) Laboratory (89.4)*	.4392	.1601	.8953	.8094
b) Non-laboratory (51.2)	.4749	.1162	.8838	.8486
c) Anatomy topic (90.6)	.4190	.1126	.8874	.8732
d) Seed topic (50.0)	.4951	.1761	.8239	.7836
e) Seed-laboratory (85.0)	.4671	.1922	.8078	.7613
non-laboratory (15.0)	.5242	.1602	.8398	.8044
f) Anatomy-laboratory (93.8)	.4112	.1259	.8741	.8323
non-laboratory (87.5)	.4252	.0988	.9012	.9245
g) Source Text:				
anatomy	.3477	.1035	.8968	.8849
seeds	.3155	.1305	.8695	.8499

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(1) Experiment descriptions are found in Appendix I
(2) To be read as entry of error correction information (bit) per input (H(X)) bit of information.
(3) Interpreted as percent of total of information in original and independent levels.

*Average scores of answers to text topic questions.

APPENDIX V

Regression Coefficients of Error Correction Information per Input Information in Transmission Channels in Memoryful and Memoryless Conditions

Exp. 1. Classroom Dialogues	r x y	ax	ay	b y x	$\overline{x}$	$\overline{y}$	y/x
A. MONOGRAM (N=30)							
H(X):Hy(X)-M^1	+.9873*	.7454	-1.9875	+2.6699	.783	+.103	.1315
H(X):Hy(X)-SS	+.9996*	.6865	-2.3878	+3.3539	.783	+.238	.3039
B. DIGRAM							
H(X):Hy(X)-M^1	+.9073*	1.7474	-3.0451	+1.7247	1.663	-.177	0
H(X):Hy(X)-M^1	+.9370*	1.5917	-3.7860	+2.3936	1.663	+.1945	.1169
C. TRIGRAM							
H(X):Hy(X) M^1	+.8838*	2.5180	-3.2978	+1.1440	2.787	+.1920	.0638
H(X):Hy(X)-SS	+.9091*	2.6764	-4.6990	+1.7711	2.787	+.2370	.0850
Exp. 2. Electric Circuit (N=12)							
A. Success							
H(X):Hy(X)-M^1	+.5508	2.5002	-3.4986	+1.8356	2.7589	+1.5656	.5674
H(X):Hy(X)-SS	+.9936*	1.9893	-5.7821	+2.9211	2.7589	+2.2769	.8252
B. Failure							
H(X):Hy(X)-M^1	+.7124*	2.0701	-1.5857	+1.2287	2.8735	+1.9449	.6768
H(X):Hy(X)-SS	+.9536*	1.9970	-5.1985	+2.7183	2.8735	+2.6205	.9119
Exp. 4. Interpretation of Phenomena							
A. MONOGRAM (N=11)							
H(X):Hy(X)-M^1	+.8967*	1.1380	-2.7946	+2.6191	1.429	+0.948	.6634
H(X):Hy(X)-SS	+.9993*	1.0575	-3.1842	+3.0093	1.429	+1.116	.7809
B. DIGRAM							
H(X):Hy(X)-M^1	+.9065*	2.0399	-7.2091	+3.6106	2.239	+0.875	.3907
H(X):Hy(X)-SS	+.9591*	1.9572	-6.4106	+3.3165	2.239	+1.015	.4533
C.TRIGRAM							
H(X):Hy(X)-M^1	+.9205*	2.8542	-4.9800	+1.8025	3.360	+1.076	.3202
H(X):Hy(X)-SS	+.9807*	3.0219	-7.7103	+2.5629	3.360	+0.901	.2681
Exp. 5. Conceptual Level Test (N=13)							
H(X):Hy(X)-M^1	+.829*	1.385	-.829	+ .810	2.242	+1.058	.4719
H(X):Hy(X)-SS	+.650*	2.044	-5.663	+3.194	2.242	+1.499	.6685
Exp. 5. Chained Recall #1 (N=13)							
H(X):Hy(X)-M^1	+.239	3.371	+.626	+ .1160	3.902	+1.078	.2762
H(X):Hy(X)-SS	+.957*	1.441	-1.534	+1.256	3.902	+3.300	.8457

---

* Significant at 5% level in descending order: 0.361, 0.576, 0.602, 0.553.

Appendix V
Continued

	r x y	ax	ay	byx	$\bar{x}$	$\bar{y}$	y/x
Exp. 6. Chained Recall #2 (N=10)							
H(X):Hy(X):M^1	+.5780	3.5798	-4.0769	+1.3992	3.9138	1.3996	.3576
H(X):Hy(X):SS	+.2371	3.5403	+1.0983	+0.4016	3.9138	2.6700	.6822
Exp. 7. Delayed Recall (N=15)							
H(X):Hy(X):M^1	-.2971	4.7793	2.0332	- .1978	4.2468	1.1932	.2809
H(X):Hy(X):SS	+.8199*	2.3444	-1.6757	1.1873	4.2468	3.3665	.7927
Exp. 8. Abstract Problem Solving (Gamma) (N=17)							
H(X):Hy(X):M^1	+.0088	4.2591	+1.6436	+ .0086	4.2742	1.6803	.3931
H(X):Hy(X):SS	+.5768*	2.8445	+ .8900	+ .7235	4.2742	3.2187	.7530
Exp. 9. Recall (N=15)							
H(X):Hy(X):M^1	+.0240	3.9604	+ .9959	+ .0130	4.0069	1.0479	.2615
H(X):Hy(X):SS	+.9554*	1.6033	-1.7147	+1.2479	4.0069	3.2855	.8199
Exp. 10. Recall (N=18)							
H(X):Hy(X):M^1	-.4435	5.2307	-3.6488	- .5204	4.7947	1.1537	.2406
H(X):Hy(X):SS	+.7623*	3.1090	-2.5118	+1.3262	4.7947	3.8469	.8023
Exp. 11. Classification Sorting (N=16)							
H(X):Hy(X):M^1	+.2872	3.5755	-2.2127	+ .9463	3.8377	1.5043	.3919
H(X):Hy(X):SS	+.5583*	2.8432	- .7504	+1.1597	3.8377	3.7001	.9641
Exp. 13. Conducting Investigations (N=20)							
H(X):Hy(X):M^1	-.1693	3.3697	+2.1355	- .0799	4.0206	+1.8143	.4512
H(X):Hy(X):SS	+.9825*	1.3690	-1.4035	+1.1046	4.0206	+3.0380	.7556

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*Significant at 5% level in descending order:
0.632, 0.514, 0.482, 0.514, 0.468, 0.497, 0.444.

APPENDIX VI

Regression Analyses for Problem Task Processing of Investigations by Groups of Seventh Grade Children by Score Earned in Laboratory and Nonlaboratory Settings (Experiment Thirteen)

Score[1], as X (N=20):	rxy	ay	byx	$\bar{x}$	$\bar{y}$
H(X)-M[1]	+.5980[2]	3.5046	+.6120		4.021
$H_x(Y)$ R.E.-M[1]					
CODE-M[1]	+.4694[2]	1.4392	+.7467		2.039
% CODE-M[1]	+.5717[2]	.3963	+.1230		.5007
a) NON-LAB. (N=10)	+.6068	.3971	+.1435	.5125	.4850
b) LAB. (N=10)	+.1388			.8938	.5165
c) ANATOMY TOPIC (N=10)	-.3181			.9062	.5525
d) SEEDS TOPIC (N=10)	+.5672	.3829	+.0827	.7000	.4490
REAL-M[1]	+.6134[2]	1.5814	+.7787		2.2066
a) NON-LAB. (=10)	+.6989[3]	1.5477	+.9323		2.1417
b) LAB. (N=10)	+.2986				2.2920
c) ANATOMY TOPIC (N=10)	-.2974				2.5180
d) SEEDS TOPIC (N=10)	+.7611[3]	1.5827	+.5205		1.8950
% REAL-M[1]	+.4212				.3659
LTM-M[1]	+.0661				.1680
% LTM-M[1]	-.0652				.0822
H(X,Y)-M[1]	+.4432[2]	5.6517	+.4370		6.0226
NOISE: IN X-M[1]	-.6491[2]	.5545	-.1214		.4570
a) NON-LAB. (N=10)	-.6433[3]	.5505	-.1229		.4752
b) LAB. (N=10)	-.6363[3]	.6557	-.2179		.4392
c) ANATOMY TOPIC (N=10)	+.1307				.4187
d) SEEDS TOPIC (N=10)	-.6081	.5561	-.0763		.4951

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[1] Score average was .7030

[2] 5% level of significance (N=20) is 0.444

[3] 5% level of significance (N=10) is 0.632

Appendix V I
Continued

	rxy	ay	byx	$\bar{x}$	$\bar{y}$
$H_y(X)$-M[1]	-.0167				1.814
$H(Y)$-M[1]	+.5593[2]	3.7322	+.5667		4.188
DEPENDENCE	-.3024				.000593
REAL-SS	-.0228				.9824
% REAL-SS					
LTM-SS	+.0022				.9824
$H_y(X)$-SS					

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[1] Score average was .7030

[2] 5% level of significance (N=20) is 0.444

[3] 5% level of significance (N=10) is 0.632

APPENDIX VII

Regression Analyses for Cognitive Task Processing by Adults, by Score Earned in Miller Analogies Test in Seven Experiments*

(Miller Analogies Test as x)

Experiment and H-measure	rxy	ay	byx	$\bar{x}$	$\bar{y}$
(5) Chained Recall, number one (N=12)					
$H_x(y)$ R.E.	-.7222[a]		-.0027	55.25	.3561
CODE	+.4372		.0021	"	2.7182
Average for six experiments (numbers 6,7,8,9,10,11) and N=13					
H(x)	+.2653			54.76	4.3244
H(x) R.E.	+.4609	-.8725	.0008	54.76	.3158
$H_x(y)$ R.E.	-.5452	-.8008	-.0218	"	.3902
CODE	+.4722	2.1677	.0203	"	2.8412
% CODE	+.6376[a]	.5271	.0033	"	.6574
% REAL-M^1	+.7063[a]	.3611	.0028	"	.5144
LTM-M^1	-.3281			"	.0385
%LTM-M^1	-.4491	.0748	-.0006	"	.0403
REAL-SS	-.4460	1.2463	-.0078	"	.8192
% REAL-SS	-.4444	.1448	-.0009	"	.0452
NOISE IN:X-M^1	-.6207[a]	.4404	-.0022	"	.3211
Average Recall, for three experiments (numbers 7,9,10) and N=13					
H(x) R.E.	+.6009[a]	.8526	.0011	54.76	.9129
$H_x(y)$ R.E.	-.7227[a]	.5043	-.0027	"	.3565
CODE	+.6514[a]	2.2002	.0203	"	3.3118
% CODE	+.8117[a]	.5493	.0033	"	.7300
REAL-M^1	+.7328[a]	2.1523	.0212	"	3.313
% REAL-M^1	+.8428[a]	.3379	.0045	"	0.5843
LTM-M^1	+.0263			"	.0282
% LTM-M^1	-.3459			"	.0257
REAL-SS	-.5755[a]	1.4494	-.0108	"	.8553
% REAL-SS	+.2617			"	.0982
NOISE IN: X-M^1	-.8246[a]	.4453	-.0033	"	.2646
$H_y(x)$-M^1	.8249[a]	1.9386	-.0141	"	1.167
$H_y(x)$-SS	-.2868				3.6254

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*For descriptions of experiments, see Appendix I, numbers 5 through 11

[a] Significant at 5% level for descending order of above tests: 0.576 (12), 0.553 (13)

Appendix VII
Continued

(Miller Analogies Test as x)

Experiment and H-Measure	rxy	ay	byx	$\bar{x}$	$\bar{y}$
Average Problem Solving, for three experiments (numbers 6,8,11) and N=13					
$H(x)$ R.E.	+.1006				.9203
$H_x(Y)$R.E.	-.1670				.4398
CODE	+.0417				2.4128
% CODE	+.1192				.5797
REAL-M^1	+.0063				2.5430
% REAL-M^1	+.2606				.4399
LTM-M^1	-.1397				.1183
% LTM-M^1	-.2113				.0567
REAL-S.S.	+.0328				.7658
% REAL-S.S.	-.1056				.0907
NOISE IN: X-M^1	+.0005				.3828
$H_y(x)$-M^1	-.1150				1.5997
$H_y(x)$-S.S.	+.0103				3.3769
Exp. 7. Delayed Recall (N=11)					
$H(x)$ R.E.	+.4027	.8281	.0014	55.09	.9045
$H_x(y)$R.E.	-.5361	.5921	.0037	"	.3875
CODE	+.4606	1.7227	.0245	"	3.0710
% CODE	+.5825	.4656	.0039	"	.6832
REAL-M^1	+.5504	1.7564	.0241	"	3.0850
% REAL-M^1	+.7378[a]	.2509	.0053	"	.5411
LTM-M^1	-.2165			"	.0876
% LTM-M^1	-.1308			"	.0341
REAL-S.S.	-.3437			"	.9084
% REAL-S.S.	-.3633			"	.1081
NOISE IN: x-M^1	-.7336[a]	.5109	-.0039	"	.2950
$H_y(x)$-M^1	-.8312[a]	2.1346	-.0158	"	1.2610
$H_y(x)$-S.S.	+.3421				3.4338
Exp. 9. Recall of Passage (N=11)					
$H_x(y)$ R.E.	+.1265				.3673
% CODE	-.0340				.7306
REAL-M^1	+.1133				3.1117
% REAL-M^1	+.0757				.5891
LTM-M^1	+.0764				.0351
% LTM-M^1	+.2884				.0156
REAL-S.S.	+.3053				.6680
% REAL-S.S.	+.2245				.0813
NOISE IN: x-M^1	-.0668				.2560
H_y (x)-M^1	-.0344				1.0524
H_y (x)-S.S.	-.0358				3.4956

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[a] Significant at 5% level for descending order of above tests: 0.602 (11), 0.553 (13)

Appendix VII
Continued

(Miller Analogies Test as x)

Experiment and H-Measure	rxy	ay	byx	$\bar{x}$	$\bar{y}$
Exp. 10. "Free" <u>Recall</u> (N=13)					
H(x) R.E.	+.7099[a]	0.8041	.00196	54.76	.9114
$H_x(y)$R.E.	-.7668[a]	-.3919	-.0113	"	.2732
CODE	+.7825[a]	1.7000	.0364	"	3.6932
%CODE	+.7410[a]	.5028	.0047	"	.7602
REAL-M^1	+.7367[a]	1.5675	.0384	"	3.671
% REAL-M^1	+.7294[a]	.2060	.0075	"	.6167
LTM-M^1	+.1984			"	-.0222
% LTM-M^1	-.4830			"	.0271
REAL-S.S.	-.6718[a]	-2.0570	-.0203	"	.9454
% REAL-S.S.	-.0345			"	.0993
NOISE IN: x-M^1	-.6779[a]	.5573	-.0057	"	.2451
$H_y(x)$-M^1	-.6576[a]	2.5013	-.0243	"	1.1700
$H_y(x)$-S.S.	.0424			"	3.8959
Exp. 11. Classification Sorting (N=11)					
H(x) R.E.	-.0604				.9850
$H_x(y)$ R.E.	-.1519				.4212
CODE	+.1432				2.2100
% CODE	+.1442				.5748
REAL-M^1	+.0735				2.3236
% REAL-M^1	+.3110				.4293
LTM-M^1	-.1843				.1136
% LTM-M^1	-.2637				.0513
REAL-S.S.	+.0542				.1174
% REAL-S.S.	+.0492				.0156
NOISE IN: x-M^1	-.0704				.3950
$H_y(x)$-M^1	-.0768				1.5244
$H_y(x)$-S.S.	-.0299				3.7315
Exp. 8. Abstract Problem Solving (N=13)					
$H_x(y)$ R.E.	+.0426			54.76	
CODE				"	2.7210
% CODE	-.7996[a]	.9365	-.0060	"	.6097
REAL-M^1	-.1149			"	2.8396
% REAL-M^1	-.0719			"	.4634
LTM-M^1	-.0778			"	.1178
% LTM-M^1	-.0107			"	.0493
REAL-S.S.	-.0870			"	1.0501
% REAL-S.S.	-.1258			"	.1193
NOISE IN: x-M^1	+.1141			"	.3637
$H_y(x)$-M^1	+.0738			"	1.6326
$H_y(x)$-S.S.	+.2913			"	3.3935

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[a] Significant at 5% level for descending order of above tests: 0.553, 0.602, 0.553

Appendix VII
Continued

(Miller Analogies Test as x)

Experiment and H-Measure	rxy	ay	byx	$\bar{x}$	$\bar{y}$
Exp. 6. Chained <u>Recall</u> (N=7)					
$H_x(y)$ R.E.	-.7811[a]	.7472	-.0049	54.86	.4780
CODE	+.7007	.6840	+.0283	"	2.236
% CODE	+.6225	.2533	+.0055	"	.5556
REAL-M^1	+.8474[a]	.5764	+.0333	"	2.401
% REAL-M^1	+.8001[a]	.0544	+.0066	"	.4170
LTM-M^1	+.0764			"	.1655
% LTM-M^1	-.3036			"	.0714
REAL-S.S.	-.1157			"	1.3035
% REAL-S.S.	-.2167			"	.1622
NOISE IN: x-M^1	-.7828[a]	.7638	-.0066	"	.4034
$H_y(x)$-M^1	-.7349	2.8596	-.0227	"	1.6140
$H_y(x)$-S.S.	+.7365	1.9372	+.0141	"	2.7125

[a] Significant at 5% level for descending order of above tests: 0.754

APPENDIX VIII

Regression Analyses for Information Theoretic Values of Problem Task Processing by Seventh Grade Children in Laboratory and Non-laboratory Settings (Experiment Thirteen) by Strengths of Dependence

	Criterion (x): (Dependence of Code Av.=.0593^{-3})		
Information Measure(y)	rxy	byx	ay
I. Total (N=20 groups)			
$H(x)$-M^1 (av.=4.0208 bits)	-.4831	-3.1234	4.2060
$H_x(y)$-M^1 (av.=1.982 bits)	+.6573	+2.0500	1.8605
CODE (av.= 2.0389 bits)			
REAL-M^1 (av. = 2.2066 bits)	-.6352	-4.7352	2.4873
% REAL-M^1 (av. = 36.60%)	-.6628	-.6617	40.52%
REAL-SS (av. = .982 bit)	-.5502	-1.2898	1.0584
NOISE-M^1 (av. = 3.7960 bits)	+.6026	+3.4457	3.5917
$H(y)$-M^1 (av. = 4.1383 bits)	-.4614	-2.6457	4.3457
II. Group Sets (N= 10 groups)	(Dependence of Code Av.=.0270^{-3})		
A. Anatomy Topic:			
$H(x)$-M^1 (av.=4.3087)	-.7232	-6.8382	4.4933
$H_x(y)$-M^1 (av.=1.9143)	+.6458	+3.1176	1.8302
REAL-M^1 (av.=2.5180)	-.8597	-11.000	2.8150
REAL-SS (av.=.9762)	-.7225	-3.2794	1.0647
$H(y)$-M^1 (av.=4.4331)	-.8568	-7.5829	4.6451
$H(y)$-SS (av.=5.2353)	-.9421	-10.4411	5.5672
$H_y(x)$-M^1 (av.=1.7905)	+.7820	+3.1176	1.6790
	(Dependence of Code Av.=.0916^{-3})		
B. Seeds Tpoic:			
REAL-SS (av.=.9882 bit)	-.8457	-1.9325	1.1652
	(Dependence of Code Av.=.0626^{-3})		
C. Laboratory:			
$H(x)$-M^1 (av.=4.0590)	-.6653	-3.7439	4.2933
CODE (av.=2.1107)	-.7523	-5.0853	2.4290
REAL-SS (av. = .9630)	-.6553	-1.1788	1.0367
$H(y)$-SS (av.=5.0220)	-.8208	-4.9268	5.3304
	(Dependence of Code Av.=.0560^{-3})		
D. Non-laboratory:			
$H_x(y)$-M^1 (av.=2.0155)	+.8137	+2.8231	1.8575
CODE (av.= 1.9671)	-.6336	-5.8778	2.2962
REAL-M^1 (av.=2.1417)	-.6299	-5.2765	2.4427
NOISE-M^1 (av.=3.8793)	+.8047	+5.0514	3.5965
$H(y)$-SS (av.=4.9845)	-.6238	-4.2765	

APPENDIX IX

Regression Analyses of Error Correction and Information Measures, for Verbal Processing of Science Object Interpretations, (Experiment Four)

Information Measures	rxy	ay	byx	$\bar{x}$	$\bar{y}$
$H(X):Hy(X)-M^1$					
MONOGRAM	+.8967	-2.7946	+2.6191	1.429	.948
DIGRAM	+.9065	-7.2091	+3.6106	2.239	.875
TRIGRAM	+.9205	-4.9800	+1.8025	3.360	1.076
$H(X):Hy(X)-SS$					
MONOGRAM	+.9993	-3.1842	+3.0093	1.429	1.116
DIGRAM	+.9591	-6.4106	+3.3165	2.239	1.015
TRIGRAM	+.9807	-7.7103	+2.5629	3.360	.901
$H_X(Y):Hy(X)-M^1$					
MONOGRAM	+.9561	-2.844	+2.8218	1.344	.948
DIGRAM	+.9534	-3.0575	+2.0600	1.909	.875
TRIGRAM	+.8965	-3.1452	+1.9006	2.221	1.076
$CODE: Hy(X)-M^1$					
MONOGRAM	-.0309$^{N.S.}$	+0.9606	-1.4990	.084	.948
DIGRAM	-.6779	+1.5661	-2.1399	.323	.875
TRIGRAM	+.2335$^{N.S.}$	+ .6073	+ .9998	1.140	1.076
$REAL:Hy(X)-M^1$					
MONOGRAM	-.9631	+1.6320	-1.4221	.481	.948
DIGRAM	-.9893	-2.5944	-1.2606	1.364	.875
TRIGRAM	-.4999$^{N.S.}$	-2.505	- .6257	2.284	1.076
$LTM:Hy(X)-M^1$					
MONOGRAM	-.9716	+1.5406	-1.4927	.397	.948
DIGRAM	-.9704	-2.6285	-1.6861	1.040	.875
TRIGRAM	-.9353	-2.8254	-1.5279	1.145	1.076
$REAL:Hy(X)-SS$					
MONOGRAM	-.9666	+1.5655	-1.4502	.313	1.116
DIGRAM	-.9992	-2.6765	-1.3581	1.223	1.015
TRIGRAM	-.9931	-4.7798	-1.5771	2.459	.901

Significance for 5% level, N=11, rxy of 0.602