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Abstract

Man engages in the continuous construction of models to describe his reality. This assumption led to some instructional research at Oakland University, Rochester, Michigan, developing and testing a systems model for the classroom. A model building process labeled message storage and retrieval was developed in some detail. Using this retrieval model as a basic form, alternative models of cognitive behavior can be constructed. A simple model of message content is one such model that forms the basis for the actual research project. It emphasizes the scientific method in course structure as opposed to the present emphasis on discipline content in the form of drill and exercise. The comparative evidence supports the conclusion that learning is facilitated by this technique which assumes that the educational goal is students who can understand and analyze. The policy implication is that the expenses incurred on current computer-assisted instruction and current pedagogical strategies must be ended in favor of more heuristic teaching methods. (LN)

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A STUDY TO EXTEND THE DEVELOPMENT AND TESTING OF A SYSTEMS MODEL OF THE CLASSROOM

March 1968

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I. INTRODUCTION

A. The Problem

> An important first step in searching for better ways of teaching is to define our terms. What is happening when a student learns? Traditional theories of education almost always answer that question in mentalistic ways. The student is said to begin with a desire to learn, a natural curiosity, of which the teacher must take advantage. The teacher must exercise the student's faculties, strengthen his reasoning powers, develop his cognitive styles and skills, let him discover strategies of inquiry. The student must acquire concepts, come to see relations, and have ideas. He must take in and store information in such a form that it can be quickly retrieved when needed. Statements of educational policy are replete with expressions of this sort. It would be a mistake to underestimate their power, for they are supported by ancient systems of psychology imbedded in our language and by vestigial cognitive theories. It is therefore hard to realize that they are either metaphors which inadequately represent the changes taking place in the student's behavior or explanatory fictions which really explain nothing. Their most serious shortcoming is that they do not tell the teacher what to do in order to bring about changes in his students or give him any satisfactory way of knowing whether he has done so. If these are indeed the tasks of the teacher, we must agree that he cannot really teach. It is even doubtful whether he can help the student learn.
>
> A much more promising approach is to look at the student's behavior--the behavior from which mentalistic states and processes are inferred and which they so inadequately describe and explain. The basic question, in its crudest form, is this: what do we want the student to do as the result of having been taught? (It is no answer to cite the examinations he is to pass, for they are only samples of his behavior, and no matter how reliable they may be, they are, we hope, very small samples indeed of what he will actually learn.) To say that we want the student to 'behave like a scientist' is on the right track, but it is only a start. For how does a scientist behave? The answer will be nothing less than an epistemology, a theory of scientific knowledge. It must in fact be more: we need an empirical description of the behavior of the scientist at work, in all its myriad forms. (Skinner, 1968.)

The shortage of adequate descriptions of the student as "scientist" becomes evident in light of recent attempts to develop computer-assisted instructional (CAI) systems. Several computer-oriented groups have recently produced systems which purport to be a step in the direction of the automated classroom. At a number of sites work is in progress aimed toward the provision of materials suitable for CAI. Work at each is aimed primarily at either (1) the development of appropriate time-sharing systems software for use with programmed instruction, or (2) the provision of materials suitable for use in programmed instruction. A considerable fraction of the latter effort is being expended on the "drill and exercise" and conventional "programmed learning" phases of the materials problem. The progress being made toward "tutorial" or "interactive" systems is marginal.

It is not difficult to visualize a short-term tragedy arising in CAI. Obvious parallels between CAI and programmed learning as practiced in textual materials indicate the possibility that programmed learning materials will simply be provided with audio-visual embellishments and transferred wholesale to CAI systems. In such a case, a theory which demands a clear specification of the desirable goal, as well as the sequence of learning tasks, will guide student development, though the statement of such goals has yet to be made in empirically meaningful terms. Of course, if such materials as are developed can be adequately presented in textual format, the additional machinery of CAI would be a costly and unnecessary apparatus. It, unfortunately, is possible that the pressing demand for and rising costs of instructional resources to serve growing numbers of students will cause systems to be implemented which effectively ignore the problem of optimal educational outcomes.

Progress has been made toward interactive systems which will potentially allow computer-mediated faculty-student interaction. Recent work by Douglas Englebart at the Stanford Research Institute is exemplary. In Englebart's theme, the computer can be used as a "super pencil" to extend man's ability to manipulate symbols on external surfaces much as present devices extended the abilities which were contingent on the quill pen. Englebart has concentrated his efforts on improving the abilities of programmers and researchers to organize their work through copywriting, editing, storing, and linking and recall systems based on cathode display, manipulation, and remote storage. If functionally similar systems are organized toward clearly specified instructional goals, it should prove possible to develop individually tailored instructional packages in the immediate presence and through the joint interaction of the instructor, the students, and the computer. The beginnings of a computer technology are present, and certainly the demand is present for such a system. If "optimal structures" and "effective sequences" are to be developed for the classroom or the computer, explicit models of the instructional process would seem a necessary requisite for such developments. Only in coordination with such models can hypotheses concerning instructional tactics and strategies be carefully developed and tested.

The report which follows outlines a model which grows out of the attempts of the writer to understand the behavior of "scientists."[1] Through such models we will eventually be able to define the desired product of the educational process in terms which are explicit enough to aid us in the design of educational strategies.

B. The Model

1. Introduction

It is a fundamental assumption of this report that man in all of his activities may be viewed as "scientific man." Implicitly or explicitly, he engages in the continuous construction of "models" of his "reality." In-

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[1]Though the writer of this report was the principal investigator for the project, and thereby accepts the responsibility for its content, credit for many of the ideas must be shared with Professor Edward Starr who served as a continuous sounding board and substantive contributor to the development of the model.

deed, his models are his reality. If we are to understand what we are attempting to accomplish in the classroom, it will be necessary for us to specify precisely what his models are, how they are constructed, and how they may be altered.

In the course of the sections which follow, an attempt will be made to describe the model-building process. In the next section, a model of a message retrieval and storage process will be discussed. In Section 3, we shall examine the type of messages which "scientific man" receives for the purpose of understanding certain fundamental problems of teaching which are implied by the nature of the messages and the storage and retrieval model. In the final part of this section, a model of the model-building process itself will be discussed.

2. Message Storage and Retrieval

The problem which is shared by the information retrieval and cognitive theorists is one of developing an adequate model for the description and manipulation of data. In the case of the information retrieval theorist, the job is the retrieval of the document most relevant to the particular query specified by the system user. In the case of the cognitive theorist, the problem may be described in quite analogous terms. An appropriate response must be "retrieved" with respect to each message which confronts the individual. As will be seen, a model which appropriately defines the boundaries of the retrieval problem is most suggestive in terms of the outlines of the cognition problem.

Assume there is available a collection of messages and that each message is described by a list of words. Consider an easily applied set of rules which might be utilized to search the collection for those messages most relevant to a given query stated in words. The rule is, count the number of words that appear in the query and that also appear in the message. The score for each message will then be represented by that count for that message. Having provided a count for each message in a collection, the collection may then be rank ordered according to these counts and, thus, according to "relevance" to the question. That is, how closely do the words in the message match the words in the query? In all that follows, the rank order of such messages is critical.

The preceding model of the retrieval process may be stated in more formal terms. Suppose a set of messages, $D = d_i$ $(i = 1, \ldots, d)$, is indexed by a set of terms, $T = t_i$ $(i = 1, \ldots, t)$. The indexed set may be represented by a d x t matrix (C) where each of the d rows represents a message, each of the t columns a term, and all matrix cells contain 1 or 0, according to whether or not the corresponding (column) term appears in the (row) message.

A simple model of information retrieval may now be represented by:

$$R = CW \tag{1}$$

where R is a d x 1 vector of weights on messages and W is a t x 1 vector of weights on terms. A weight of, say, 1 might be assigned to each term in W in which the searcher is interested and a zero to each term of no interest. The multiplication of the matrix (C) by the vector W so defined then yields the vector R such that the message containing the largest number of terms receives the highest weight, the message with the second largest number of terms the second highest weight, and so forth. The model above is a generalization of the majority of the information retrieval models currently in use. It covers the class of so-called "coordinate systems" and assumes, of course, that the weight to be applied to a given message is a linear function of the weights on the terms contained in the message. It is now possible to move to a specific interpretation of the analogy between the retrieval and learning processes. For the purposes of the discussion which follows, C may be viewed as the set of constructs (messages) which makes up the student's total image (collection). Thus each row (message) becomes a construct and the total matrix becomes an image (collection).

Consider the factors which will influence the ordering of the constructs in response to queries, or messages. Suppose, once again, that d constructs were to be indexed over t terms. Suppose, further, that each construct contains a different number of terms and that no construct contains a term which appears in any other construct. If the probability of term A appearing in a message were equal to the probability of term B appearing in a message, then the most efficient ordering of the constructs would depend only on the absolute number of terms appearing in the constructs.

The idea of an efficient retrieval order is important in light of the astronomical number of messages which are received by a human being in any relatively short period of time. Any element which has appeared a sufficient number of times in a message for it to be stored in long-term memory would produce, if used alone, a block of messages which would probably swamp short-term memory. Thus "important" elements and the messages containing them must occupy high order positions in any block of messages retrieved. On the other hand, "unimportant" elements and the messages containing them should eventually descend "beyond recall."

By simple extension, only three additional rules will influence the retrieval ordering of constructs in a simple coordinate model. These rules are (1) the probability of a given term appearing in a message, (2) the number of terms contained in each construct, and (3) the relative frequency with which terms appear in the entire collection.

Learning and teaching may now be described as the processes by which new terms come to be added to the old constructs and/or new constructs come to be added to the set already resident in the system. A brief side excursion will be made to examine some of the difficulties which would be encountered in teaching a model student who acts as if he were organized as a simple coordinate retrieval system. There are two general classes of problems which will be encountered in teaching such a student, if the implications of the model are correct. First, there are the difficulties of inserting or erasing a term or terms in already resident messages. The second, and most important, problem for present purposes is one of anticipating the impact of any changes in or additions to the constructs on the retrieval order of the full set of constructs in the image.

Consider the difficulty of inserting a specific theory into the student's image. A theory may be defined as, through a compare operation, providing the means for "predicting" the existence of te_s which may not be contained in an incoming message. One example of such a theory is the chemist's periodic table of the elements which has indicated to those who have worked with it the existence of numerous elements long before they were isolated.

Suppose that the construct which the student is attempting to add to his image contains but one term and suppose further that the term is a new one in his vocabulary. It follows that the construct will be retrievable only by a message containing that specific term and that, if that term is the only one in the request, the construct will occupy the first position in the retrieval order. To expand, the relative frequencies of the several terms in an individual's image will not necessarily match the overall relative frequencies of those terms in the messages sent to him, since each message sent will not necessarily result in the addition of a construct to his image. We may thus distinguish between the construct-term frequency and the message-term frequency. It has been argued that the factors affecting the retrieval order are the number of terms appearing in the individual constructs, the construct-term frequency, and the message-term frequency. The unambiguous effect of an increase in the relative frequency of a term in the system is to lower the long-term retrieval order rank of the constructs containing that term. On the other hand, the addition of a term to a specific construct has the unambiguous effect of raising its rank in the long-term retrieval order. From the point of view of efficiency and assuming that the construct-term frequency and the number of terms per construct remain constant, the unambiguous effect of a relative increase in the use of a message term should be to raise the long-term retrieval order rank of the constructs containing it. These contrary effects of the added use of terms engage fundamental problems of instruction in a way that is both rigorous and intuitively clear.

For example, the student, confronting the economist for the first time, apparently carries with him a construct which contains at least the idea that "cost" is equivalent to "price." Daily common usage (high message-term frequency), the theory suggests, will insure the relatively high retrieval order rank of that construct by maintaining its relative query-term frequency. Thus each time another student asks him: "How much did that textbook cost?," the construct's relative retrieval rank will be maintained or improved. Thus posed, the potential magnitude of the problem of "teaching" becomes apparent. Not only must any construct which is to replace this defective construct be implanted but it must provide or anticipate a source of maintenance for its retrieval order. Unless the economist imagines that either he or other economists will continually communicate with the student, the angry once-and-for-all assertion that "price is not equivalent to cost" will hardly suffice.

It is the further implication of the theory that the repeated addition of identical constructs with the same terms contained in them will not suffice. Indeed, such additions would hamper further use of the terms involved by driving down their rank. Thus much as the table of the elements, any theory, be it the theory of the consumption function, the theory of cartels, or whatever, the position of the construct, or "idea," must be improved in the retrieval order through the generation of additional associated terms in the inquiry process.

Leaving aside for a moment the further implications of the coordinate model, turn now to a most useful extension of that model. It will be seen below that a fourth factor may influence the retrieval order in addition to the three discussed above.

In the retrieval model just described there is no means for developing connections between stored constructs. As a consequence, the need for virtually unlimited storage capacity cannot be avoided except possibly by postulating a process by which messages decay with time. However, the basic model may be altered slightly to reduce the need for storage capacity, with the side benefit of allowing each new message to modify slightly the contents of the entire image.

Suppose that for W in equation (1) we substitute the following equation:

$$W = \lambda C^{T}R + Q \qquad (2)$$

Substituting in equation (1) we get:

$$R = C\left(\lambda C^{T}R + Q\right) \qquad (3)$$

which reduces to:

$$R = C\left(I - \lambda C^{T}C\right)^{-1}Q \qquad (4)$$

Equation (4) lies at the heart of the class of so-called linear associative retrieval systems defined by Guilliano and Jones (1963).

If the value of λ is 0, Q in equation (4) is interpreted as being the same as W in equation (1). If, however, λ is some positive constant, each element of Q will be modified according to the contents of the inverse matrix in the parentheses.

If the row sums in the matrix (C) are normalized to sum to 1 before the indicated operations are carried out, the inverse matrix is a term-by-term matrix, each cell of which contains the value of an associative bond between the pair of corresponding terms. Thus each row may be interpreted as a thesaurus of the row terms. The cell values may range from 0 to .99 where 0 represents the absence of a discernible relationship between the pair of terms and .99 suggests that the pair has nearly perfect complementarity, in which case one term never appears without the other. The range of cell values may result either from such structural relationships as those between the words "missile" and "nose cone" or from such synonymous relationships as exist between "missile" and "rocket."

The chief gain of the addition of the associative matrix is to allow terms which do not appear in the original message to influence the retrieval order of the messages or constructs. Thus the fourth important factor is added to the three factors discussed above as important in determining the retrieval order of a message. That fourth factor is the extent to which the specific terms in the message appear as terms associated with the specific terms in the query. Thus the larger the number of terms which are associated with terms in the query and the greater the strength of their associative bonds, the higher will be the expected retrieval order of the messages containing the associated terms. There is, in addition, the important gain mentioned previously, to which gain we may now turn.

At first glance, the image must now include two separate units: (1) the construct collection, and (2) the association matrix which defines the strength of the associative bonds between all pairs of terms. On further consideration, the construct collection appears to be not only inefficient but unnecessary. The evidence of any previously entered "significant" relationship remains as a bond linking pairs of terms, and demands that incoming queries be evaluated in terms of those bond pairs. For example, if a message containing the separate terms "P," "D," and "Q" has been received in the past, it is implied that the thesaurus contains associative bonds between the three pairs, "PD," "PQ," and "DQ." Thus, while for many purposes it may be desirable to keep the original collection of messages, it is not necessary to keep it if the central concern is discerning the relationship between terms in the messages.

We are led to conclude that the demand for efficient storage and recall implies that four factors will govern the position in the retrieval order of a particular construct: (1) the probability that a given element will appear in a message, (2) the number of elements or terms contained in each construct, (3) the relative frequency with which elements appear in the entire collection, and (4) the number of terms associated with terms in the query. The retrieval model just discussed has considerable promise as a basic model around which alternative models of cognitive behavior could be constructed. In the following section, several primitive operations will be defined, which operations can be related to the retrieval model in simple ways to produce a model of learning.

3. A Simple Model of Message Content

Assume that the "goal" of a student is to maximize utility. Leaving aside for the moment the problem of measuring utility, let us further assume that he is continuously bombarded with "messages." The elements of such messages must necessarily be structured from data bits gathered from the five senses. Our concern in the present section will be to examine the nature of these sense messages which the utility maximizing student faces and some of the implications which the retrieval model of the last section has for the way in which these messages are treated by the cognitive apparatus. In order to proceed, it is necessary to define a series of terms which have obvious relevance to the retrieval model but which will not, in this exposition, be tied to the retrieval model explicitly.

The student has a list of instruments by which he may pursue his goal of utility maximization. Our list will include: read, write, transcribe, memorize, and classify. Assume that we may distinguish between long-term memory and short-term memory. Read, for our purposes, is defined as the process by which a "message" of external origin reaches short-term memory. Write is defined as the process by which a "message" held in short-term memory is displayed externally. We may compound the processes of reading and writing in a special way to define transcribe. Thus the word transcribe means that the message written is a message just read. Memorize is defined as repeated reading of a single message, resulting in the storage of that message in long-term memory. The classify process is defined as comparing a message in short-term memory with messages in long-term memory. Based on the results of the comparison, terms are added to or subtracted from the short-term message.

Ideally, the educational process may assist the student in optimally mixing these activities. Thus he would learn when he needs to read; he would learn when it was necessary to memorize; he would learn that writing would help him to clarify his own thoughts; and he would know that he had not classified a problem enough to provide an articulate answer. Unfortunately, numerous matters "intervene" between the student and his goal. Consider grades and time as such "intervening variables." Grades have become--and not without some good reasons--a prime measure of the student's progress toward his "goal." In fact, they are so often used as a measure that they have in some cases become a "goal" for many students. It is not at all difficult to imagine that a particular mix of read, memorize, write, and transcribe has yielded maximum grades for some students. Similarly, the press of time in the educational system may cause the student to conclude that, if there is a set of alternative ways of looking at matters, he could not grasp very many alternatives within a short time.

With the model of a single student defined, we may return to a discussion of the treatment of messages by the student. If a message just read contains no elements which match with the elements of a message stored previously in long-term memory, such a message is a nonsense message. Repeated transcription would cause, by definition, the storage of such a message in long-term memory. However, that at least one common element exists in the two messages would seem a necessary condition for classification to take place. Fundamental to such a classification process, and much of what follows, is the idea that the common elements may be given a name symbolic of their commonality.

The ability to name implies the existence of a resultant message with at least one element in it, which element could not have been received from an external source. The element is, of course, the name itself. Repeated reading alone, from our definitions, cannot cause such an element to be stored in long-term memory. To have the ability to display externally elements held in short-term memory (the ability to write) is a necessary but not a sufficient condition to allow the long-term storage of names. The ability to repeatedly display such elements (transcription) is a sufficient ability for this purpose. It is a corollary that names must be displayed externally if they are to be learned.

The messages read can now be of two varieties -- messages with names and messages without names. The elements of the first type of message may be defined as symbols. The elements of the second type of message may be referred to as impressions. In addition, messages containing only symbols may themselves be named, giving rise to elements which we shall define as abstractions.

We may now examine, in light of our earlier discussions, a problem of considerable significance to the learning of abstractions. The problem is that of maintaining a high retrieval order in long-term memory for abstractions. "Symbol" terms will maintain an order based on the repeated reading of messages. Abstractions, on the other hand, behave perversely. To the extent that the messages read contain abstractions, the messages read will sustain the retrieval order of the abstraction and will link it with any other abstraction or symbol contained in the message. The occurrence of abstractions as abstractions may be relatively too rare to sustain the order of particular abstractions.

By an assumption that symbols and abstractions may be used in messages simultaneously (once they have been stored in long-term memory), still a second difficulty arises. Many abstractions have historically been formed from terms whose "message-term frequency" is based on their use as symbols. A failure of the sender of the message to distinguish between the two types of terms may cause erroneous linkages to be formed or may sustain the retrieval order of the wrong term. Yet another difficulty exists in the structure of the associative bonds.

Whatever the normalization and computation scheme chosen, the numerator of the fraction forming an associative bond will be increased by any "strengthening of the relationship" between the pair of terms it connects. On the other hand, any appearance of the one term without a simultaneous appearance of the other term will cause a decline in the fraction. Thus the use of the words "firm," "capital," "money," and many others in economics as abstractions may be seriously hampered by their continuing occurrence as symbols in everyday usage.

Assume, again, that the student is organized as the associative retrieval system of the previous section. If he is so organized, we may define his "reality," or his "image" of the world, as being the network of associative bonds in his unique matrix. Terms which he does not "have" and associations which he does not "see" are not part of his "reality." The only "reality" he understands and acts on is that which he can "see" and "understand." While the physics or physiology of writing words on paper, the history, chemistry, or sociology of ink, alphabets, typewriters, reading, grammar, or desks may be very important pieces of someone's unique image of the world, it is not a part of the image of the student, if he does not possess the appropriate set of associative bonds.

We may now define the teaching (learning) process as the implanting (acquiring) of new terms and/or the construction of new or the restructuring of old associative bonds. Each of these activities defines the formation of a new "reality." Ignore for the time being the particular subject matter one is teaching. The specifics of the discipline or the peculiarities of the material to be covered are only second-order tactical problems. The first vital piece of any teaching strategy may well be an awareness of and a sensitivity to the existence and the importance of the student's own set of associative bonds. Their sets of bonds are the basic stuff available to work with, on, and through. Secondly, perhaps there must be specification by the teacher of exactly what he is trying to accomplish. It is to this second element of strategy we will now turn.

We are concerned with developing order-of-magnitude estimates of the size of the educational undertaking with respect to a given student and, further, with seeking some tactical guidelines. We may now examine some of the implications of the model for these two purposes. Before proceeding, we may note that there are three general tactical options open to the instructor: (1) he may attempt to provide new terms for the student and is, by implication, engaged in the construction of new associative bonds, (2) he may attempt to work on the old associative bonds with which the student has been equipped, and (3) he may attempt to help the student to explore thinking his way through sets of associative bonds. The last option arises because each "message" containing three terms implies three associative bonds, each message of four terms implies six associative bonds, and so forth. It is this latter consideration which may assist us in developing some notion of the size of the task.

It is helpful to examine further the simple arithmetic of the number of associative bonds generated by specific numbers of terms. In general, the number of distinct associative bonds in a symmetrical matrix such as we have been discussing will be equal to $(N^2 - N)/2$ where N is the number of rows and columns in the matrix. Thus if a student is expected to understand all the relationships between each pair of thirty terms, he will be forced to explicitly examine 435 associative bonds. Put another way, an instructor who attempts to get the student to work with thirty new terms is asking the student to examine roughly a bond every five minutes in 45 to 50-minute meetings. The foregoing caricature of the student would appear to be consistent with the abysmal results often obtained in the teaching of courses in which the subject matter of the discipline provides the focus of the study. Subject matter courses in this case may be contrasted with courses concerned primarily with theory and methodology.

The problem of distinguishing between symbols and abstractions, the problem of maintaining the retrieval order of abstractions, and the arithmetic of associative bonds all suggest the need for a simple set of abstractions, which set is relatively free of direct symbolic connection and whose retrieval order is maintained by the expanding set of symbols and abstractions to which it is related. It is important to note that it is possible to rely on an expanding set of symbols and abstractions because of the introduction of the associative weighting. An example of such a set of abstractions which seems a meritorious candidate for work in the social sciences is developed rather fully in the following section.

4. A Model of a Model Builder

A simple "language" may be constructed based on the idea of describing certain primitive abstractions that are utilized broadly by social scientists in general and economists in particular. For the reader, that language may be defined recursively in terms of some of the paragraphs in section 2. Essentially it is argued that numerous terms in the social sciences are concerned with "institutions," "instrument variables," "intervening variables," and "goals." Institutions are defined as decision-making units and are described exhaustively by the instruments available to them. Instruments are defined as variables whose levels must be chosen by the institution, which choices will affect the institution's progress toward its goal. Intervening variables are defined as instruments under the control of other institutions.

Parameters are defined as set outside the system. The intervening variable may influence the progress of the institution toward its goal by impeding or assisting, but lies outside the direct control of the institution. A goal is defined as a preferred state of some variable or set of variables.

Some illustrations will clarify the use of this conceptual structure. The Federal government may be viewed as an institution which has the instruments of taxation and subsidization by which it may pursue the goal of increasing the rate of economic growth. The firm (institution) may be viewed as seeking to maximize its profits (goal) by means of variation in its output, research and development expenditures, and expenditures on capital equipment (instruments). Consumers (institutions) may be viewed as maximizing utility (goal) by consuming, saving, giving, and learning (instruments). From the standpoint of each of these institutions, the instruments of each of the other institutions may be viewed as intervening variables. Thus the consumer's decision to consume and save may intervene in the firm's attempts to invest and the government's attempts to tax. In addition, for the purposes of any particular model of economic development, such factors as population growth, the state of the level of technology, education, and the endowment of natural resources may be taken as intervening variables determined outside the system (parameters).

It is critical and of over-riding importance to recognize that these illustrations were chosen absolutely arbitrarily. The immense power of these four abstractions lies in their adaptability to use in describing any such model regardless of the perspective from which the user operates. Thus, in the illustration above, natural resources were fixed parametrically. In a model of the petroleum exploration process, they would serve as a goal. In a model of oil-field operations, they would be an instrument, and perhaps (?) to a chemist they would be an institution with goals determined by the laws of Boyle and Charles.

Model-building activities in the social sciences may now be described in terms of: (1) attempts to define institutions, instruments, intervening variables, and goals, (2) attempts to specify the directions, magnitudes, and functional forms relating instruments, intervening variables, and goals, and (3) attempts to find and test measures of the relationships specified in these models.

There are three varieties of activity in which a model builder may engage which are closely related to model building but which are not formally part of it. Model builders engage in purely descriptive activities, symbolic logic and mathematics, and mathematical statistics. These activities relate in obvious ways to the three varieties of model building activities described above, but are not the substance of model building. With the classification schema in mind, we may now turn to the outline of a rough model of a model builder.

It is convenient to view two interacting individuals as two black boxes engaged in the continuous interchange of messages. Thus, in Figure 1, individual 1 transmits a message to individual 2. Individual 2 stores the message as a construct (or as associative bonds), retrieves an "appropriate response," and transmits a message to individual 1. Individual 1 stores the message, retrieves an appropriate response, transmits a message to individual 2, and so on.

The messages of either party to the interaction may be defined in terms of the classifications developed above. Messages as transmitted may contain a complete statement defining the institutions, instruments, intervening

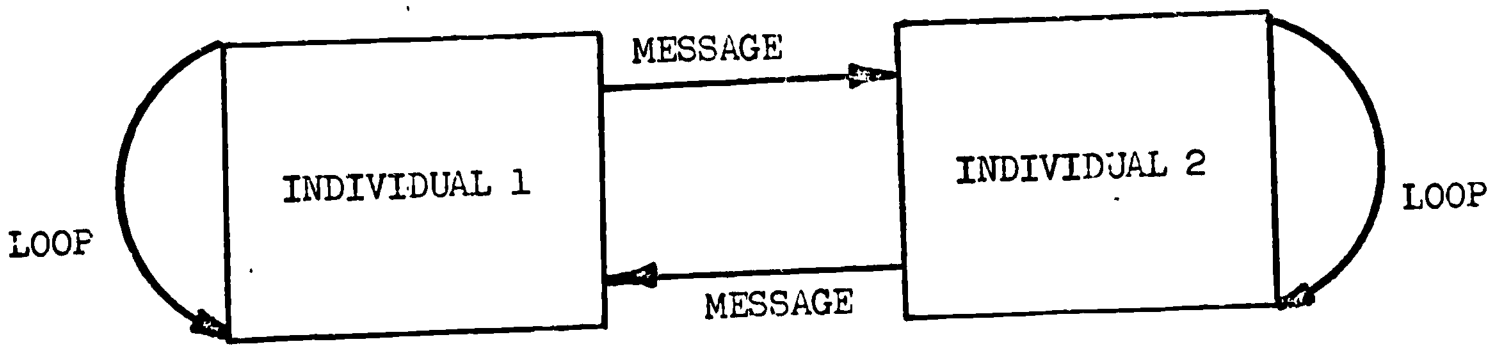


FIGURE 1

variables, and goals. On the other hand, consistent with the previous definition of a theory, the message may contain simply the data that an act was performed or an outcome occurred, and the message would be received as any combination of subsets, etc. Given the associative nature of the cognitive model, the message recipient will "fill in the blanks." A homey analogy of mother and child will illustrate. The baby cries, conveying only the message that he has utilized an instrument. The mother must make an inference regarding the intervening variables and goals involved in the baby's (institution's) cry (instrument). She fills in the missing symbols (builds a theory) so as to predict which of a set of variables is intervening on the child (hunger, wetness, or danger). Her level of success is uniquely determined by her ability to make correct predictions. A dry and hungry baby is still a hungry baby. At the most primitive level, such inferences are indeed predictions, and serve to define the basically "scientific" nature of everyday man or woman as it is perceived in this document.

It may be assumed that in the learning process so described the goals of the individual come to be associated with particular instruments available to the individual and with certain intervening variables. The message that a goal has not been reached may be defined as a problem (the dry baby still cries). Such a message may be assumed to simultaneously retrieve an instrument for the individual's response. By our definition, we may distinguish between two responses to a particular problem so defined--the response of the implicit model builder, whom we have just described, and the response of the explicit model builder. The latter may be distinguished from the former in that classification systems are explicitly included among the instruments of the latter, while they are not included among the instruments of the former. The simple process depicted in Figure 1 is thus modified. Rather than simply receive a message, retrieve a message, and display the message, the individual may be depicted as (1) receiving a message, (2) retrieving a classification system (abstraction), (3) transmitting a message to himself which includes the terms of the classification system and the terms of the message received, and (4) displaying externally a new message based on the results of a message retrieved by both the original message and the classification system. Strictly speaking, it would be hypothesized that the inclusion of classification systems in the query of step (3) is common to both the implicit model builder and the explicit model builder. The latter, however, may be viewed as having found classification systems for the development and testing of classification systems.

The following several tables display a plausible set of results from the simple inclusion of the institution-instrument-intervening-goal classification in a retrieval query. These tables are intended to convey something of the array of variables involved in a description of the economic interaction between three institutions. In each of the cases, the instrument variables of one institution are candidates for inclusion as intervening variables for the other institutions.

In order for a model builder to move from such lists (thesauri) to an explicit model of a particular set of not previously explored institutional interactions, he must carry out at least three operations. We will assume that these operations are carried through in short-term memory. It will be seen in the analysis which follows that these short-term memory operations may be defined so as to demand memory operations identical with those of long-term memory. In order to proceed, first, the institutions must be defined in terms of their instruments; second, the units of measurement must be defined for all instruments, intervening variables, and goals; and, third, the network of simple direct relations between all instruments, intervening variables, and goals for

Table 1a

The Consumer as an Institution

Instrumental Variables	Intervening Variables	Goals
Work	Location	Maximize Utility*
Consumption	Wage Rates	
Investment	Time	
Migration	Taxes	
Reproduction	Prices	
Invention	Interest Rates	
Imitation	Subsidies	
Giving	Age	
Leisure	Sex	
Saving	Information	
Hoarding	Health	
Bidding	Wealth	
Borrowing	Occupation	
Ornamentation	Trust	

*Utility is used as an ordinal measure of the satisfaction gained from the exercise of the instrument variables. It is some index of such components as risk, security, justice, beauty, status, knowledge, and control, each appropriately scaled.

Table 1b

The Firm As an Institution

Instrumental Variables	Intervening Variables	Goals
Inputs	Tariffs	Profit Maximization
Outputs	Taxes	Sales Maximization
Advertising	Subsidies	Growth Maximization
Research & Development	Industry Prices	Maximize Share of Market
Investment	Population Growth	Cost Minimization
	Inventive Activity	Maximize Social Benefits
	Interest Rates	Managerial Utility Maximization
	Capital Requirements	
	Time	
	Patents	
	Input Prices	

Table 1c

A Government As an Institution

Instrumental Variables	Intervening Variables	Goals
Spending	Population	Growth of Per Capita Income
Taxation	Natural Resources	Price Stability
War	Technology	Reduced Unemployment
Direct Contrcls	Gold in Ground	
Moral Suasion		

the total system must be defined. The model eventually will relate, for each institution in the system, changes in an instrument or set of instruments to a movement toward a goal or set of goals. If the units of measurement and the network of simple relations are defined, the network of interactions can be deduced and a particular instrument's effect on a particular goal and the effects of a set of instruments on a goal or set of goals can be determined. Though such determinations do not specify the magnitude or direction of the effect, they lay bare the implications of the simple logic used in their construction. Thus changes in consumer giving, saving, and moving are related to the government's goals of full employment and price stability. A more detailed example will serve to both clarify these elementary model-building operations and put in explicit form the model discussed in section 2.

Once again, for the sake of simplicity, the goal and instruments of but a single institution are included, and it is assumed that grades, time, class size, and factor "x" intervene as the student attempts to maximize his utility. The functional forms of parametric models ultimately demand that the classification of variables by units of measure be consistent. At the most primitive level, the model builder must insure that the variables are at least measurable in theory. In the model of Table 2a, utility, thinking, and transcribing serve to illustrate the problem. Transcription was defined earlier as a cycle involving reading and writing. The addition of the retrieval model casts some doubt on the validity of this formulation in that it suggests a necessary intermediate retrieval operation between reading and writing. Nevertheless, the difficulties involved in measuring transcription are apparent. Similarly, classifying is a compound process involving: (1) cycles of reading, (2) retrieving, and (3) writing. The process of simply defining these variables and arraying them in the forms of Table 2a may alert the explicit model builder to a range of the inconsistencies in his formulation.

TABLE 2a

X_1 = Utility

X_2 = Discussion

X_3 = Reading

X_4 = Memorization

X_5 = Writing

X_6 = Transcription

X_7 = Classification

X_8 = Grades

X_9 = Time

X_{10} = Class Size

X_{11} = Factor

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
X_1		1						1	1		
X_2	1									1	
X_3		1				1	1		1		
X_4						1			1		
X_5		1				1	1	1	1		
X_6	1								1		
X_7	1	1							1		1
X_8					1						
X_9											
X_{10}											
X_{11}											

The specification of the simple, direct relations between pairs of variables, as existing or not existing in Table 2a, again calls into question the meaning of the measures defined. In examining these relations, the more sophisticated theorist may move on to the specification of the functional form of the multivariate relation. However, a simpler approach for the purposes of exploring the implications of Table 2a lies in treating the successive products of Table 2a as a matrix. These products can be carried out to reveal second, third, and higher order interaction effects between all variables. Recall that these products normalized and summed are an associative matrix. Tables 2b and 2c display the second and third order interactions, respectively. Table 2d displays, in one table, all three levels of interaction; the second cell in row X_5 indicates that X_2 affects X_5 directly, once through a two-step path and four times through a three-step path.

The reader may note that at least the following properties of the model are revealed by an inspection of Table 2d:

1. The slow and relatively small implied response of the system to changes in X_{11} (a variable of unknown dimensions which can be used to affect any process but which was arbitrarily viewed as affecting only classification).
2. Strong second and third order effects of the variables which directly influence utility.
3. The relatively powerful implied effect of class size (X_{10}) on all variables, all of which must operate through the effect of class size (X_{10}) on discussion (X_2).

These interactions may alternatively be examined in graph form, alleviating the necessity for the successive multiplications. Figure 2a displays only the variables which affect X_1. Figure 2b presents a relatively simple

TABLE 2b

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
X_1	1				1					1	
X_2		1						1	1		
X_3	3	1							1	1	1
X_4	1								1		
X_5	3	1						1	1	1	1
X_6		1						1	1		
X_7	1	1						1	1	1	
X_8		1				1	1	1	1		
X_9											
X_{10}											
X_{11}											

TABLE 2c

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
X_1		2				1	1	2	2		
X_2	1				1					1	
X_3	1	3						3	3	1	
X_4		1						1	1		
X_5	1	4				1	1	4	4	1	
X_6	1				1					1	
X_7	1	1			1			1	1	1	
X_8	3	1						1	1	1	1
X_9											
X_{10}											
X_{11}											

TABLE 2d

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
X_1	b=1	a=1, c=2			b=1	c=1	c=1	a=1, c=2	a=1, c=2	b=1	
X_2	a=1, c=1	b=1			c=1			b=1	b=1	a=1, c=1	
X_3	b=3, c=1	a=1, b=1, c=3				a=1	a=1	c=3	a=1, b=1, c=3	b=1, c=1	b=1
X_4	b=1	c=1				a=1		c=1	a=1, b=1, c=1		
X_5	b=3, c=1	a=1, b=1, c=4				a=1, c=1	a=1, c=1	a=1, b=1, c=4	a=1, b=1, c=4	b=1, c=1	b=1
X_6	a=1, c=1	b=1			c=1			b=1	a=1, b=1	c=1	
X_7	a=1, b=1, c=1	a=1, b=1, c=1			c=1			b=1, c=1	a=1, b=1, c=1	b=1, c=1	a=1
X_8	c=3	b=1, c=1			a=1	b=1	b=1	b=1, c=1	b=1, c=1	c=1	c=1
X_9											
X_{10}											
X_{11}											

Key (cell layout, column X_i, row X_j):

a	
b	c

a = direct relationship between X_i and X_j

b = number of two-step paths between X_i and X_j

c = number of three-step paths between X_i and X_j

FIGURE 2a

INTERACTION OF VARIABLES AFFECTING VARIABLE X_1

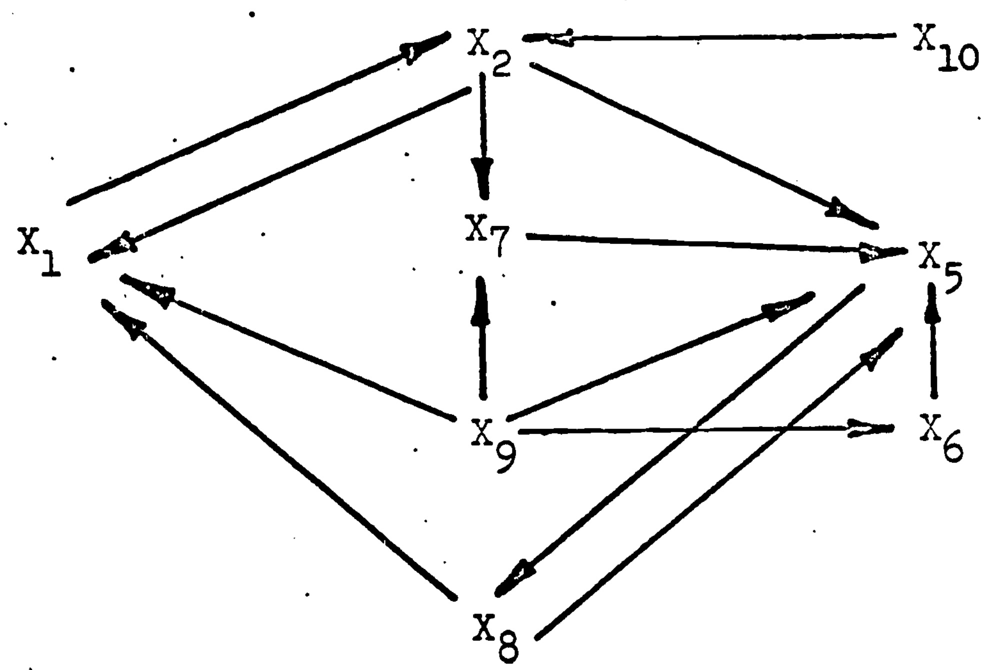
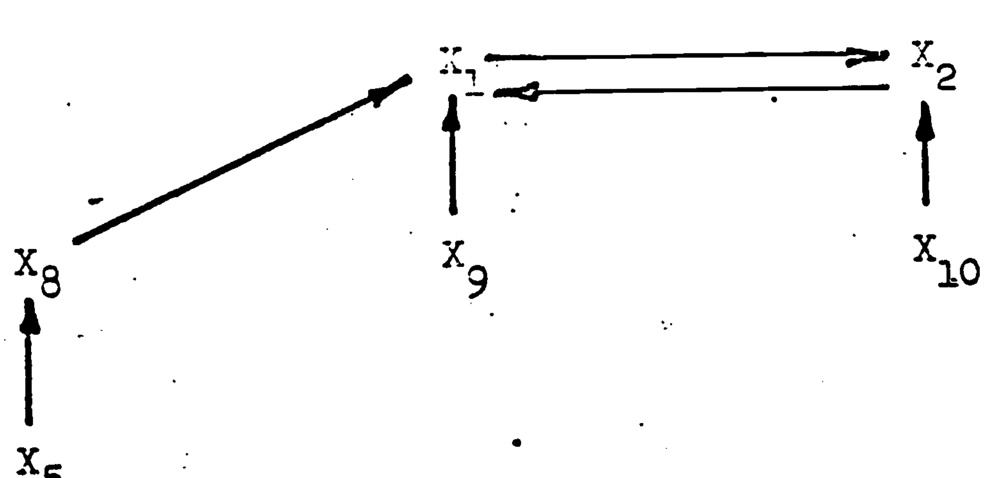


FIGURE 2b

INTERACTION OF VARIABLES AFFECTING VARIABLE X_2



model which may be used to determine the level of discussion (X_2). It may be noted that similar simple models may be graphed for those remaining variables which are dependent variables.

It is the case that as each row in the matrix of Table 2d defines the total system from the perspective of the variable labeled on the row as a dependent variable, the graphs present those same views through variables X_1 and X_2, respectively. From the point of view of the analyst, such row graphs may aid substantially in defining the set of variables which needs to be included in the model of a particular subsystem, the inclusion of which is based on the simple binary logic of the original statement of the total system.

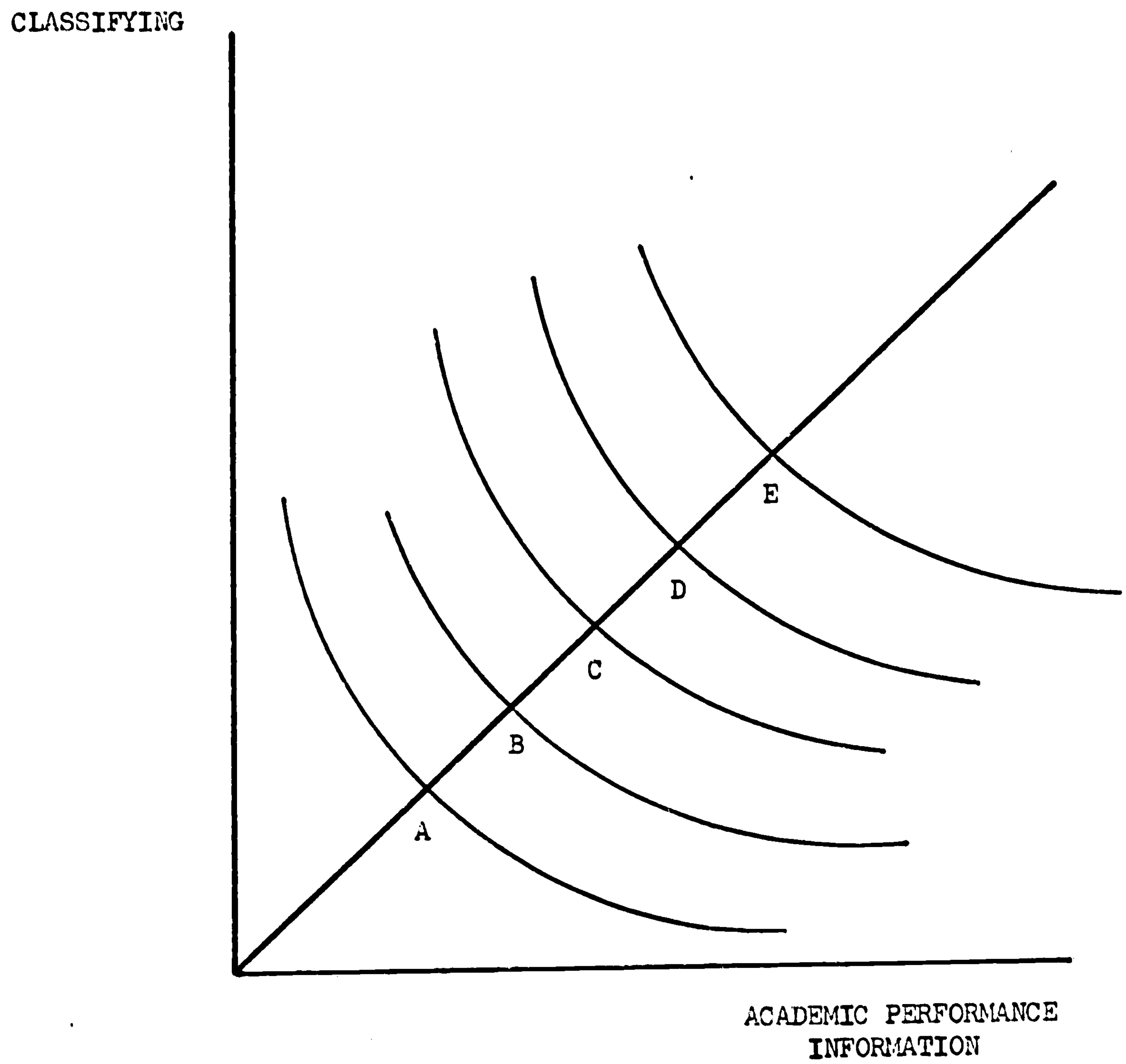
More important than the particulars of that model, the three elementary processes which have just been discussed would appear to correspond closely to and make explicit the processes conventionally followed by the seasoned decision maker. The graphs are the messages which qualitatively relate a change in an instrument or set of instruments to a movement toward a goal or set of goals. Indeed, for a particular goal, the entire set of relevant instruments and intervening variables can be separated from those variables which are not relevant. They may alternatively provide the input to a further set of classification processes necessary to the explicit determination of functional relationships between variables.

It may be further observed that the process by which the row graphs are developed is precisely the same as the retrieval process itself. Thus the cognitive processes involved in explicit model building would, by the model, require no structural apparatus different from that required by the general cognitive process of the retrieval model.

On the one hand, storage and retrieval capacity is necessary if the individual is to provide messages in response to those he receives from his environment. On the other hand, an identical process would have to manipulate the retrieved lists into the row graphs to provide the response message of the explicit model builder. It may be hypothesized that the functioning of the former process will prove dependent on the previously acquired information stored by the individual. If, however, the mind is viewed as a limited capacity machine, the storage of information beyond a certain quantity may prove a hindrance to the manipulative capacity (defined as the ability to utilize classification systems). Thus for any finite speed (measured, say, in bits/nano-second) at which the retrieval operations are presumed to take place, capacity may be devoted either to the storage of information or to the "space" necessary for the computation of row graphs. If the conjecture holds, it would be expected that the map like that of the three dimensional surface displayed in Figure 3 would relate "information previously acquired" to "classifying capacity" and academic performance. The latter assumptions would, of course, be easily disturbed by a range of motivational and perceptual variables which are beyond the scope of the present work.

A movement along the horizontal axis of Figure 3 represents successively higher levels of information previously acquired by the individual. Similarly, a movement along the vertical axis (or any line parallel to it) represents successively higher levels of the ability to classify. Any movement to the northeast, as through points A, B, C, D, and E, encounters the contour lines, denoting successively higher levels of academic performance. It may here be noted for later reference that movements to the northwest and southeast along the contour lines display alternative combinations of information storage and classifying capacity which will yield the same level of academic performance.

FIGURE 3



II. METHOD

A major portion of the activities of the principal investigator was aimed at the development of the model in the preceding section. The testing and empirical investigations which have taken place thus far have been, for the most part, informal in view of the time and monetary constraints on the project. However, an attempt has been made to provide an answer to three questions which have grown out of the view of symbolic model building expressed in the previous section.

First, if students were presented with the view of model building suggested above, could they utilize that view to clarify their understanding of the writings of professional economists? Secondly, if the classification were used as a means for abstracting articles in the field of economics, would it yield reasonable term thesauri and document retrieval orders if used in a conventional linear associative retrieval system? Finally, is academic performance related to the amount of information previously stored by the student and his ability to classify, as is suggested by the model of the previous section?

For two years, Oakland University has offered each entering freshman the opportunity to participate in a range of "exploratories." While offered by the faculties of many disciplines, these seminar-sized courses are not introductory courses in particular disciplines. Rather, the subject matter of the course is left to the individual instructor, and, as the title implies, he is free to range over a broad spectrum of topics which he feels will be of interest to the students. In order to determine whether or not the students could work with the broad range of works of economists as they appear in the professional literature and then utilize their understanding for pursuing independent topics, an exploratory entitled "Theories and Queries" was offered to 20 Oakland freshmen in the fall term of 1967. In "T&Q," freshmen were presented with the description of model building discussed in the previous sections. They were then asked to abstract randomly selected articles from the 55 major journals in the literature of economics and to develop and present a paper for the course, utilizing their knowledge of symbolic model building. Paralleling the activities of the freshmen in the "T&Q" exploratory, two student assistants in the economics department converted some 1500 abstracts from the Journal of Economic Abstracts into the same form. In each abstract, the institution or institutions, intervening variables, and goals were identified. The resulting abstracts were then utilized to construct thesauri.

Finally, simple measures on several variables appearing in the model of the previous section were obtained in order to explore the hypothesis that student performance is a function of (1) the information previously acquired, and (2) the student's ability to classify information. The MLAT-PTB was used as a measure of the student's ability to classify. The CQT-I was selected as a measure of the information previously acquired. The student's Fall 1968 cumulative grade point average at the university was used as a rough measure of academic performance. The scores for 64 males in a random sample of students who entered Oakland in the Fall of 1966 were examined.

III. RESULTS

A. The Theories and Queries Exploratory

During the first eight weeks of a 15-week term, students were asked to abstract one randomly selected article from the Journal of Economic Abstracts for each class meeting. A set of 77 abstracts was prepared independently by a senior economics major (now a Woodrow Wilson designate) who had been working with the classification scheme for several months, and her work was compared with a set of such abstracts prepared by a freshman mathematics student with an average university performance. The results obtained compared quite closely on the major features noted in the performance of the freshman exploratory students. Before commenting on the performance of the exploratory students, it is helpful to compare the performance of the senior economics major with that of the freshman mathematics major.

Table 3 presents the comparative results of the work of the two students. The senior student found that 31 of the articles abstracted contained models, while the freshman student found that 59 of the articles abstracted contained models. The distinction between their performances provides an interesting commentary on their comparative use of the classification system. The freshman failed to abstract but four of the articles abstracted by the senior. There were 28 articles abstracted by the freshman which were classified by the senior as not containing models. Fully 19 of these articles were classified by the senior as involving purely descriptive material. Of the remaining, eight were classified in mathematics and one in statistics.

With respect to the 27 articles which both students abstracted, the freshman failed to name two out of 33 institutions named by the senior, one out of 50 instruments, 19 out of 84 intervening variables, and five out of 38 goals.

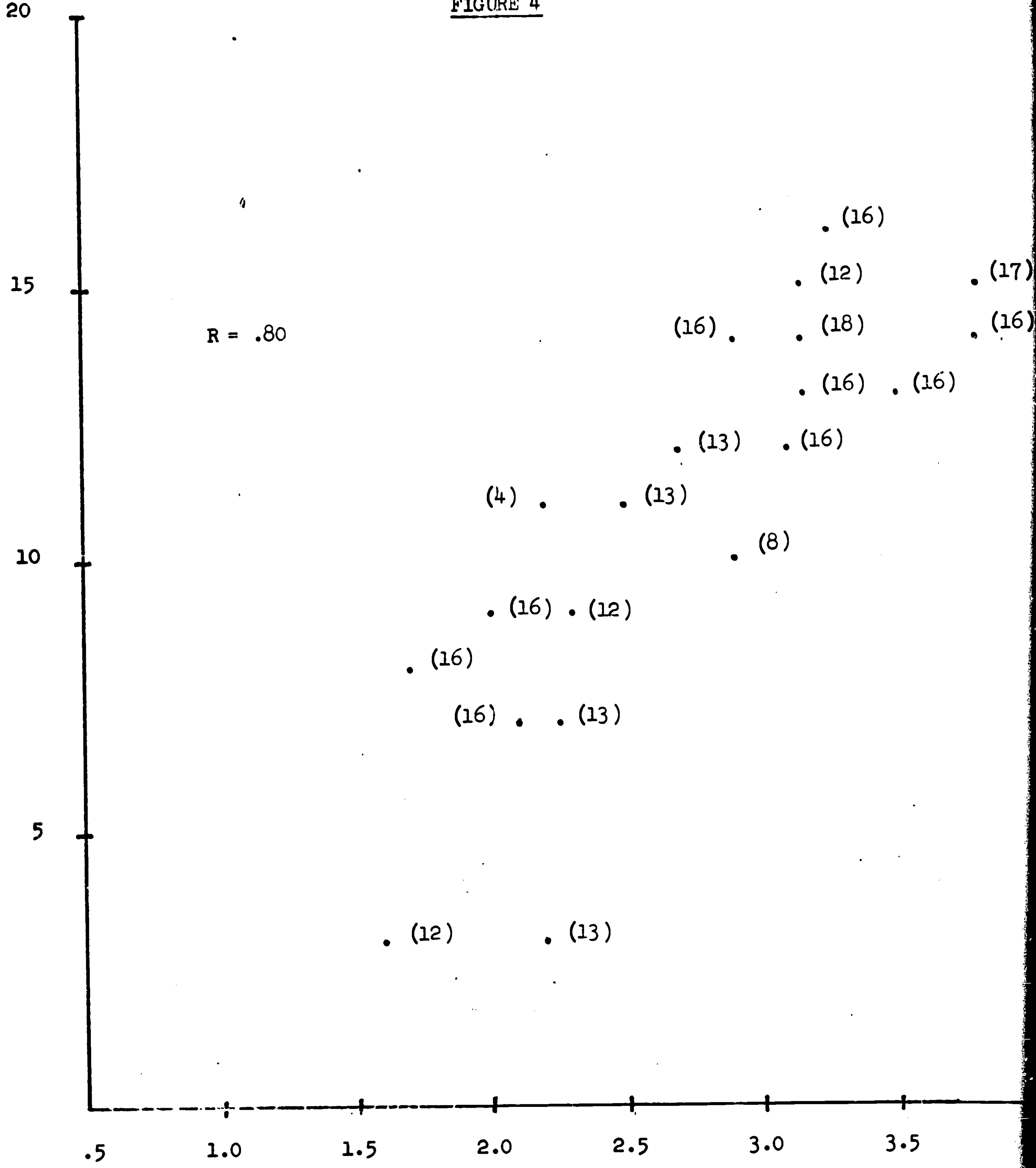
The performance of the freshman student assistant discussed compares quite closely with the performance of the students in the freshman exploratory. It may be noted here, and can be observed in Figure 4, that the performance of the exploratory students in correctly abstracting was quite closely related to their cumulative performances in courses other than the exploratory during the same term. The vertical axis of Figure 4 measures the number of abstracts substantially correctly from the point of view of the instructor, and the horizontal axis measures the student's cumulative grade point average in other courses during the same term. The abstracts prepared by the exploratory stu-

Table 3

77 Abstracts

	Senior Student	Freshman Student
I. Models	31	59
II. Descriptions	31	8
III. Mathematical	14	4
IV. Statistical	4	2

FIGURE 4


20
15
10
5
R = .80
(16)
(12)
(17)
(16)
(18)
(16)
(16)
(16)
(13)
(16)
(4)
(13)
(8)
(16)
(12)
(16)
(16)
(13)
(12)
(13)
.5
1.0
1.5
2.0
2.5
3.0
3.5

dents were not compared with those prepared by the student assistants, since those abstracts were returned to the students for further study.

B. The Thesauri

At the beginning of the project, it was anticipated that the associative thesauri would serve several direct and continuing purposes in a resultant CAI system. In the evolution of the project, that view has been modified. Their chief use, consistent with the models in section 1, seems to be as heuristic devices used from time to time to suggest new variables, goals, or institutions which might be included in the particular model-building effort being attempted by the user. The thesauri of several "institution-type" terms are displayed in Table 4.

C. Student Performance

Finally, we may report on the results of the tests of the hypothesis regarding student performance. On Figure 5 the MLAT-PTB percentile score is measured on the vertical axis and the CQT-I percentile score is measured on the horizontal axis. Beside the plot of each observation is found the raw cumulative G.P.A. of the student.

Along the 45-degree ray from the origin in Figure 6 are plotted and labeled the median values of all scores to the northeast and southwest of the given points. To the northwest and southeast of each point are found the median values of observations falling in those quadrants. The distributions from which the percentile scores were computed are found in Appendix A.

IV. DISCUSSION

A. The Theories and Queries Exploratory

The most striking result coming out of the comparison of abstracts discussed above can be seen in the large number of articles seen to contain models by the freshman, whereas the senior classified the articles as descriptive in nature.

TABLE 4

Bank	Central	82	Condition	35
	Reserve Requirements	70	Customer	35
	Banks	55	Money	35
	Ceiling	52	Movement	35
	Treasury	49	Foreign Exchange	33
	Money Supply	45	Rates	32
	Loan	43	Monetary	31
	Credit	40	Liquid	30
	Velocity	37	Market	30
	Reserve	36	Minimum	30
Consumer	Utility	59	Process	15
	Maximization	33	Savings	15
	Income Taxes	28	Bonds	14
	Income	27	Cash Balances	14
	Maximum	24	Discount Rate	14
	Property	20	Expenditure	14
	Relief Payments	20	Propensity to Consume	14
	Per	18	Propensity	14
	Education	17	Standard of Living	14
	Demand	15	Stock	14
Entrepreneur	Attitude	32	Human	18
	Conflict	32	Production Costs	18
	Activity	24	Size of Firm	18
	Commercial	22	Growth	17
	Formation	22	Fiscal	16
	Legal	22	Underdeveloped	16
	Budget	18	Incentive	13
	Creation	18	Investment	13
	Economic	18	Organization	13
	Export	18	Develop	12
Firm	Output	37	Capital	22
	Profit	35	Growth	22
	Profits	33	Discount	21
	Maximization	29	Resources	21
	Inputs	28	Input	19
	Long-run	25	Scale	19
	Investment	24	Utility	19
	Plant	23	Industry Supply	18
	Product	23	Payout	18
	Returns	23	Dividends	17

TABLE 4 (Cont'd.)

Government	Stability	34	Price	22
	Policy	33	Private	22
	Economic Growth	32	Tax	22
	Expenditure.	30	Spending	21
	Investment	28	Business Firms	20
	Fiscal Policy	27	Economic Activity	20
	Control	26	Employment	20
	Economic	23	Entrepreneur	20
	Industry	23	National	20
	Income	22	Purchase	20

FIGURE 5

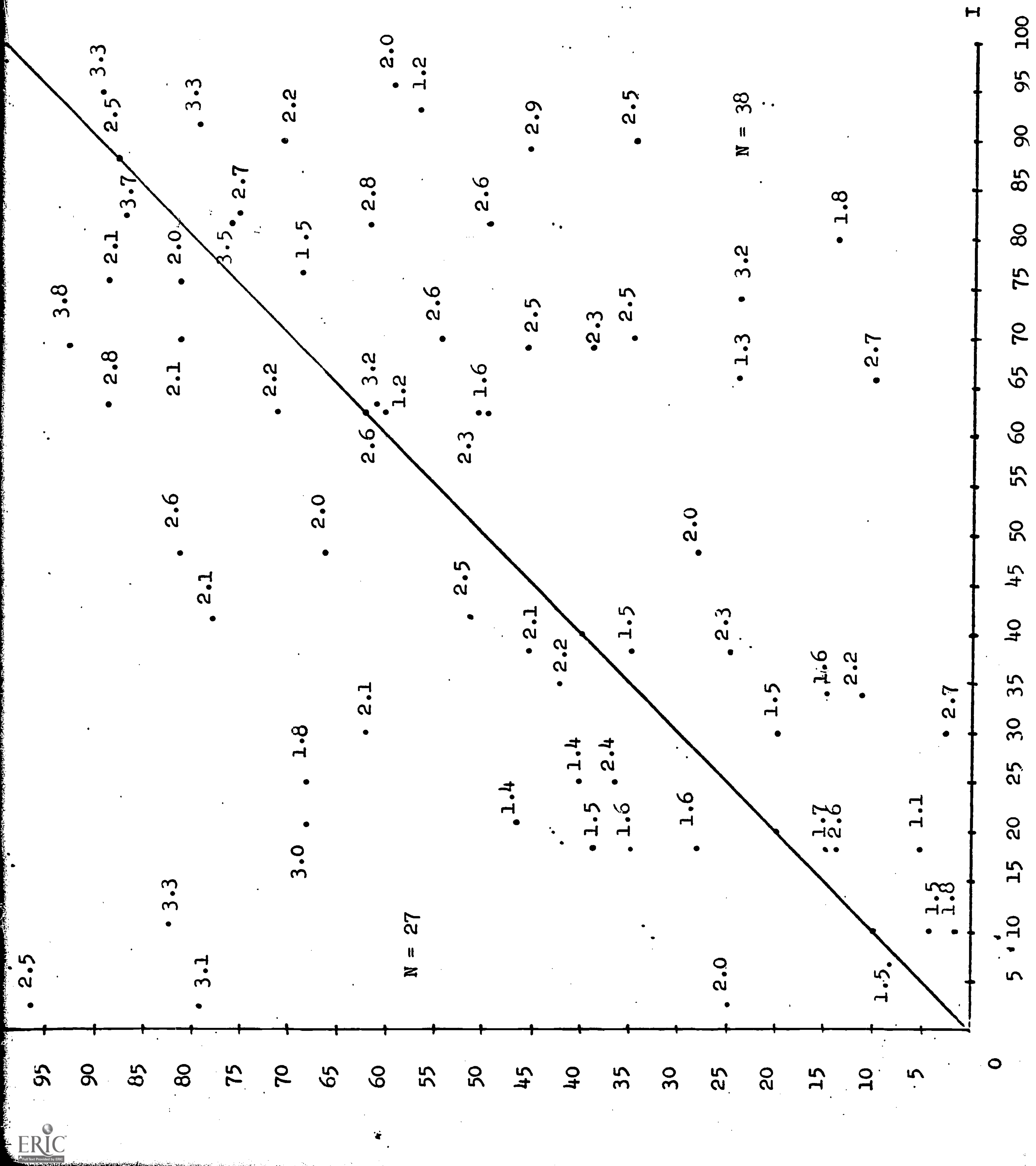
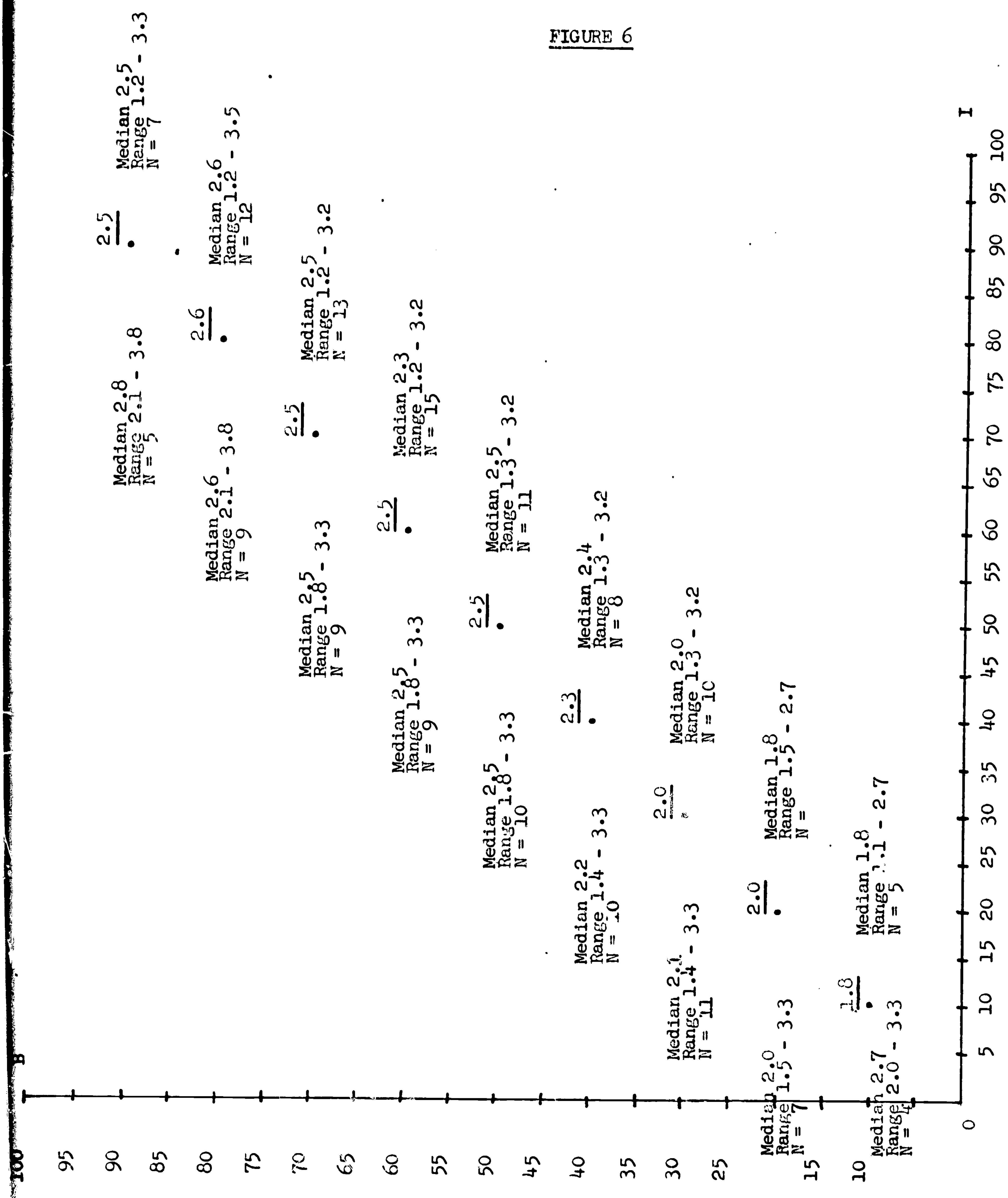


FIGURE 6


B
I
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
15
10
0
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Median 2.8
Range 2.1 - 3.8
N = 5
2.5
Median 2.5
Range 1.2 - 3.3
N = 7
Median 2.6
Range 2.1 - 3.8
N = 9
2.6
Median 2.6
Range 1.2 - 3.5
N = 12
Median 2.5
Range 1.8 - 3.3
N = 9
2.5
Median 2.5
Range 1.2 - 3.2
N = 13
Median 2.5
Range 1.8 - 3.3
N = 9
2.5
Median 2.3
Range 1.2 - 3.2
N = 15
Median 2.5
Range 1.8 - 3.3
N = 10
2.5
Median 2.5
Range 1.3 - 3.2
N = 11
Median 2.2
Range 1.4 - 3.3
2.3
Median 2.4
Range 1.3 - 3.2
N = 8
Range 1.4 - 3.3
N = 11
2.0
Median 2.0
Range 1.3 - 3.2
Range 1.5 - 3.3
N = 7
2.0
Median 1.8
Range 1.5 - 2.7
N =
1.8
Median 1.8
N = 5
Range 2.0 - 3.3

The differences would seem to lie in the rather more strict criterion applied by the senior in deciding what constitutes a model. Put another way, the freshman found models where none existed. One may view classification as a necessary but not sufficient condition for the construction of models. Given that the tools of mathematics and statistics were not available to the freshman, it would appear in retrospect that this type of error is precisely the type of error which might have been expected, given the relative development of the two students in their understanding of the models of the social sciences.

The work of one exploratory student provides an outstanding example of the "style" of thought which it seems possible to induce. The central topic chosen was a study of the Conquistadores' conflict with the Aztecs. The senior student's treatment of the main topic (chosen by the student without faculty consultation) is illustrated by her choice of intervening variables, among which were: the training of the Conquistadores, the immunity of the Conquistadores to the range of European diseases which they carried to the Aztecs and their Indian slaves, and the sun god legend used by the Conquistadores. Quite as striking is the range of peripheral research topics generated and pursued by the same student in the course of the research for the paper. For example, she became intrigued with the logistics and planning of 17th century intercontinental colonization expeditions to a sufficient extent that she turned in several "models" in which she attempted to examine such problems as the allocation of tonnage capacity between foodstuffs, men, crew members, water, trading supplies, weaponry, and the like. These items were viewed as instruments available to expeditions (institutions) having survival goals.

In general, it can be said, on the basis of the evidence available from the freshman exploratory that the classification system is a promising pedagogical tool and that work with it tends to support the conclusion that learning is greatly facilitated by abstractions of that sort.

B. The Thesauri

The thesauri constructed from the 1500 abstracts prepared by the student assistants show clearly the results of replacing semantic associations with associations based on the institution-instrument-intervening variable-goal model.[2] The resulting thesauri tend to reflect, from the viewpoint of an economist, the a priori importance which might be attached to the terms in constructing models of these particular institutions. The seven-character thesauri may be compared to the four-character thesauri of Appendix C in order to note the considerable improvement in word associations. Essentially, the semantic associations of the four-term thesauri have been exchanged for relations between variables.

C. Student Performance

The results of the study of student performance are encouraging, if somewhat ambiguous. The general shape of the surface supports the hypothesis. If treated as a scatter diagram, the probable correlation between MLAT-PTB and CQT-I scores would appear to be very low. There is a tendency for classification to yield higher payoffs than information. Distortions of the surface are due primarily to failures of the students to utilize their "full potential" rather than failures of over-performance.

In earlier unreported work by the writer, it was possible to distinguish by Markov analysis between "tired" students and "bored" students. Corrections for these two factors for groups to the southeast and northwest of the 45-degree ray may well yield considerable corrections on the surface.

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[2] By way of an aside, certain difficulties of a mechanical sort were encountered. It became clear in the use of the thesauri that four-character roots were not sufficiently indicative of the individual word to be easily used by students (see Appendix B). Therefore, the system was re-programmed to a seven-character root.

V. CONCLUSIONS

On the basis of the work and discussion which have gone into this report, two types of conclusions seem warranted. The first type of conclusion relates to the further development and testing of the particular model discussed in the report. The second type relates to the development of further work in the area of computer-assisted instructional systems.

The classroom experiences of the writer suggest that the model provides sound guidelines for the development of courses in the social sciences and may be useful elsewhere as well. Five general areas have been covered, with apparent carry-over in a one-semester course. We may touch briefly on each of these five areas.

First, the institution-instrument-intervening variable-goal classification allows the discussion of an immense range of topics in the classroom if the primary aim of the instructor is to insure that students acquire sufficient familiarity with the classification to use it successfully. Indeed, a sufficiently adventurous instructor may allow the class to generate daily topics on an ad hoc basis with virtual certainty that the class will not stray far. The topics may range from "linus as a security maximizer" to "the instruments of the black militant" in a single hour.

Second, the problem of "narrowing a topic" for study is eased considerably for students by the judicious construction of binary matrices and their attendant row graphs. The explicit use of these devices also forces students into a badly needed examination of the precision of their own language. As a side benefit, the distinction between "partial" and "general" systems is apparent very early in the classroom discussions. In a later work it will be shown, following the work of Herbert Simon and Tjalling Koopmans that "causal ordering" in simultaneous equation systems and the so-called "identification problem" may be easily handled graphically.

Third, a number of students have come to characterize the classification scheme as a very useful shorthand by which they may take notes on the exposition of a variety of subjects. In their note taking, they attempt to construct the speaker's "model of reality" for comparison with other models including their own.

Fourth, the role of mathematics and statistics in the definition and testing of models can be dealt with easily and directly. Since the row graph models are devoid of indications of magnitude and direction, the students may be easily led to ask questions about the signs and magnitudes of "partial derivatives" which they are unable to compute. With the appropriate background in "how mathematicians think" immense progress would seem possible.

Fifth, the particular models of a given discipline are easily handled by students. There is further a strong tendency to compare and contrast those models in the context of the general framework.

Though many of the parts have been put in place, there remains a considerable amount of work to be done before the model of the model builder presented can be said to be a direct guide for the planning of pedagogical strategies. However, to the extent that it is a good predictive model, the inescapable conclusion is that we must turn from classroom discussions of the contents or subject matter of our disciplines to classroom discussions of the heuristic devices by which practitioners proceed. In essence, there must be coat hooks before the students are asked to hang up their coats. By our earlier discussion of the difficulty of dealing with ambiguous abstractions, these "coat hooks" cannot be the particular models used by the practitioners, but must be in the form of meta-models.

The results obtained thus far, theoretical as well as practical, suggest that the surface has just been scratched in an area of immense potential reward, both for researchers and students. It is an area where the good intentions of the practitioner must confront the paradoxes of human organization if new strategies for dealing with obvious educational problems are to be honed.

Turn finally to the question of CAI systems. On the basis of the research reported here, it is not yet clear what role the computer can fruitfully play in the instructional process. Indeed, given the desired end product, many of our current strategies, both CAI and classroom, may do greater harm than good. If the computer allows us to reach more people at lower cost, we should perhaps forego the economy until the specifications of the product can be clearly written.

With the foregoing gloomy caveat in mind, there would seem to be several hopeful paths which are worthy of exploration: 1) the possibilities of computer-mediated interaction (CMI) should be explored rather fully with an eye to the generation of "learning communities" in which "model matching" is used to link individuals together in the discussion of problems and ideas they have in common, 2) the development of computer-assisted explanation systems should be extended to modeling languages and contexts, and 3) editing, linking, and graphic recall systems should be simplified and developed for use with large-scale data and document-retrieval systems. It would seem that these several systems will have benefits for all which are independent of the final outcome of work in CAI.

VI. SUMMARY

The study is directed toward the question, "What do we want the student to do as a result of having been taught?" The final product of the study is a model of a model builder. The basic ingredients of the model are a linear associative information retrieval system and a simple abstract system by which the models of the social sciences may be classified according to substantive criteria.

If the goal of the educational process is to produce students who can understand and analyze, it is concluded that many of the conventional strategies which have been developed for that purpose are counterproductive. The model provides several strategic alternatives and the study discusses relatively informal attempts to test and evaluate these alternatives.

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APPENDIX A

DISTRIBUTIONS FOR MLAT-B

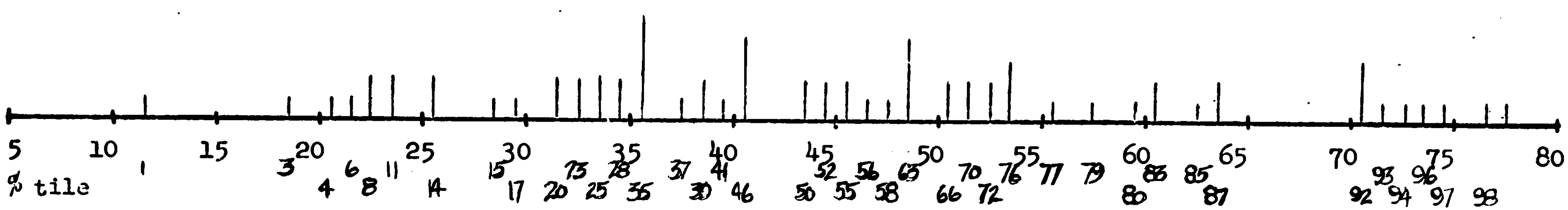
and

CQT-I SCORING

APPENDIX A

FREQUENCY AND PERCENTILE DISTRIBUTIONS OF MLAT INFORMATION SCORES

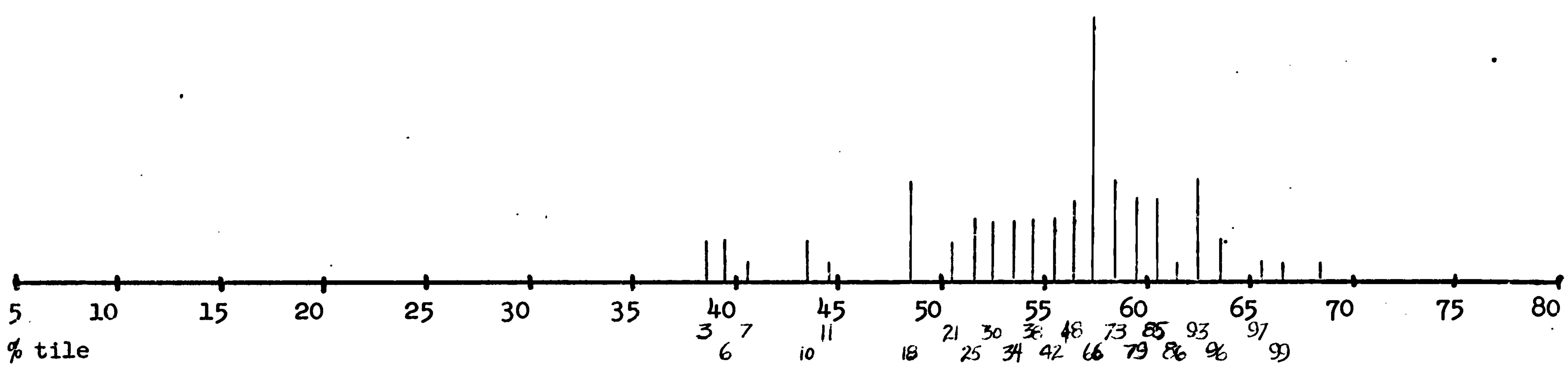
MLAT PART B



APPENDIX A

FREQUENCY AND PERCENTILE DISTRIBUTIONS OF CQT INFORMATION SCORES

CQT-I



APPENDIX B

COMPRESSED STRING DICTIONARIES

A compressed string dictionary (CSD) may be defined as a dictionary of words in which each word is represented by the first x characters of the word plus the length of the word in digits. Thus, in a CSD, the word "compressed" would appear as "COMP10" if x = 4, "COMPR10" if x = 5, and so forth. Several features of these dictionaries which make them useful in the manipulation of natural language by computer are given below:

1) economy of storage requirements
2) predictability of storage requirements
3) manipulability by string processing languages
4) the ease with which a log search of the dictionary may be conducted

The memo which follows provides an initial look at the problems encountered in constructing a 713-word dictionary covering the discipline of economics. The memo is concerned with:

1) the level of ambiguity as it relates to the selection of x where ambiguity is defined in terms of indistinguishable strings
2) the impact of ambiguity as it relates to the selection of x
3) considerations in the resolution of ambiguity

The Level of Ambiguity

The dictionary on x = 4 resulted in the following ambiguities, classified according to the number of words involved:

Table 1

	2 Word	3 Word	4 Word
x = 4	43	8	2
x = 4.5	33	7	0
x = 5	27	6	0
x = 5.5	25	6	0

The Impact of Ambiguity

The level of ambiguity is persistent in part but also declining in part over the length of the character strings tested. For that reason, it is useful to distinguish between two types of ambiguity, namely, that which is caused by the identity of root words and that which is not. Table 2 classifies the ambiguities of Table 1 into those ambiguities caused by root strings and those caused by non-root strings. Table 3 summarizes the results in Table 2 in a somewhat more convenient form.

Table 2

x = 4

	AMBIGUITIES		
	2 Word	3 Word	4 Word
Root	25	5	0
Non-root	18	3	2

x = 4.5

	AMBIGUITIES		
	2 Word	3 Word	4 Word
Root	25	5	0
Non-root	9	2	0

x = 5

	AMBIGUITIES		
	2 Word	3 Word	4 Word
Root	23	5	0
Non-root	4	1	0

x = 5.5

	AMBIGUITIES		
	2 Word	3 Word	4 Word
Root	22	5	0
Non-root	3	1	0

Table 3

Total Ambiguous Word Strings

	Total	Root	Non-root
x = 4	118	65	53
x = 4.5	89	65	24
x = 5	75	61	14
x = 5.5	68	59	9

The Reduction of Ambiguity

Two methods may be used for the reduction or elimination of ambiguity. Either additional characters and half-characters may be added or ambiguous words tagged and an exception routine written to store, say, x characters of information on each version of the ambiguous word. The choice would seem to depend on the importance of ambiguity reduction in the root words. Reduction in the ambiguity of root words by adding additional terms seems unfeasible. However, if term endings are not important, say, for grammatical purposes, the ambiguity may be utilized to shorten the necessary dictionary. In such a case, non-root ambiguity may be reduced to the desired level by incrementing x. If, on the other hand, root word ambiguity is important, the gain at the margin from the incrementation of x is very low, as may be seen in Table 4 derived from Table 3.

Table 4

Compressed String Length Interval	Reduction in the Number of Ambiguous Words
x = 4 - 4.5	29
x = 4.5 - 5	14
x = 5 - 5.5	7

In the latter case, an exception routine seems worthwhile.

The items on which the foregoing analysis was based are as follows:

WORD-FREQUENCY DATA

TOTAL WORDS: 713

TOTAL AMBIGUITIES: 53

2-WORD AMBIGUITIES: 43

ROOT: 27

Administration - Administrative
Allocating - Allocation
Association - Associative
Capitalism - Capitalist
Collection - Collective
Criteria - Critical
Discrimination - Discriminatory
Distribution - Distributive
Earners - Earnings
Economical - Economists
Electricity - Electrician
Employees - Employers
Evaluation - Evaluating
Expanding - Expansion
Industrial - Industries
Labor - Labour
Legislature - Legislative
Management - Managerial
Manufacturers - Manufacturing
Optimal - Optimum
Policies - Politics
Produce - Product
Producer - Products
Producers - Producing
Restriction - Restrictive
Retailers - Retailing
Theorems - Theories

NON-ROOT: 16

Block - Blocs
Commercial - Commission
Comparison - Competitor
Consumer - Constant
Consistent - Constraint
Consequences - Conservation
Interest - Internal
Integrated - Interstate
Inventions - Investment
Inventories - Investments
Liner - Lines
Outlets - Outlook
Plans - Plant
Principal - Principle
Property - Proposal
Research - Reserves

3-WORD AMBIGUITIES: 8

ROOT: 5

Economics - Economies - Economist
Employed - Employee - Employer
Operating - Operation - Operative
Regulating - Regulation - Regulatory
Relating - Relation - Relative

NON-ROOT: 3

Basic - Basin - Basis
Centers - Central - Century
Invention - Inventors - Inventory

WORD-FREQUENCY DATA (cont'd.)

4-WORD AMBIGUITIES: 2

ROOT: 0

NON-ROOT: 2

Committee - Commodity - Communist - Community
Comparative - Competitive - Competition - Composition

APPENDIX C

Bank	Holding	14	Determinism	05
	Regulations	13	Factors	05
	Loans	12	Discrimination	04
	Discount	10	Rise	04
	Regulation	08	Money	04
	Mergers	07	Banking	04
	Commission	06	Expansion	04
	Company	06	Investment	04
	Empirical	06	Allocation	04
	Rate	06	Behavior	04
Consumer	Decomposability	17	Measurement	07
	Elasticities	12	Conditions	06
	Price	12	Demand	06
	Functions	10	Effect	06
	Insurance	09	Pension	05
	Prices	08	Scale	05
	Chances	07	Travel	05
	Level	07	Benefit	05
	Index	07	Canadian	05
	Buying	07	Interest	05
Entrepreneur	Sociological	09		
	Firm	06		
	Models	04		
	Economic	03		
	Social	02		
Firm	Size	36	Entrepreneur	06
	Product	11	Base	06
	Inputs	09	Market	05
	Oligopoly	09	Enterprise	05
	Monopolistic	09	Growth	05
	Jurisdiction	09	Antitrust	05
	Output	07	Information	05
	Nationalized	07	Reserve	05
	Rate	06	Large	05
	Opportunity	06	Investment	04

APPENDIX C (Cont'd.)

Government	Local	15	Acceleration	04
	Securities	10	Small	04
	Revenue	07	Holding	04
	Businessman	07	Impact	04
	Anthropology	06	Contrast	04
	Developed	06	Independent	04
	Effectiveness	05	Printing	04
	Systems	05	Contracts	04
	Period	05	Determinants	04
	Shares	04	Industry	04

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