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AUTHOR Scandura, Joseph M.
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ABSTRACT

This article has two main theses: (1) Qualitative improvements in education will not come about as a result of rhetoric or superficial proposals for solutions made by the social-activist breed of educator, but rather as a result of a deeper understanding of the teaching-learning process, and the development and use of new and better principles of educational design. (2) Theoretical bases for qualitative improvements in educational design already exist and should be made more readily available to educational researchers. Among the problems considered are: content analysis, performance testing, "far" transfer, learning processes, developmental stages, and instructional methods. These problems are reviewed with respect to the theory of structural learning, and existing or potential theory-based resolutions of these problems are proposed. The paper is organized as follows: (1) a brief review of the recent history of educational psychology; (2) a partial list of open problems in educational design; (3) a summary of some of the more immediately relevant portions of the author's recent theory of structural learning; and (4) a discussion of how these open problems have, could, or might be resolved via the structural learning theory. (Author/CS)

THE RESOLUTION OF INSTRUCTIONAL PROBLEMS: RHETORIC, RESEARCH, OR THEORY?

Abstract

The major purpose of this article is to identify some of the problems in education that have been discussed in the current literature, and to indicate how these problems have been solved or might reasonably be attacked. Among the problems considered are: content analysis, performance testing, "far" transfer, learning processes, developmental stages, and instructional methods. These problems are reviewed with respect to the theory of structural learning, and existing or potential theory-based resolutions of these problems are proposed.

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THE RESOLUTION OF INSTRUCTIONAL PROBLEMS: RHETORIC, RESEARCH, OR THEORY?*

Joseph M. Scandura
MERG and University of Pennsylvania

This article has two main theses: One qualitative improvements in education will not come about as a result of rhetoric or superficial proposals for solution made by the social-activist breed of educator, but rather as a result of a deeper understanding of the teaching-learning process, and the development and use of new and better principles of educational design. Two, theoretical bases for qualitative improvements in educational design already exist and should be made more readily available to educational researchers.

More specifically, the paper is organized as follows: (1) a brief review of the recent history of educational psychology, and concomittent social pressures, to provide a perspective for later remarks; (2) a partial list of open problems in educational design; (3) a summary of some of the more immediately relevant portions of the author's recent theory of structural learning; and (4) a discussion of how these open problems have, could, or might be resolved via the structural learning theory. The topics covered in this article include:

(a) a basic distinction between knowledge and behavior,

(b) the foundations for a performance (criterion reference) test theory,

(c) how the performance test theory provides a basis for more efficient instruction,

(d) an analysis of why some students skip over prerequisites whereas others do not, together with guidelines as to how transfer can purposefully be built into a curriculum,

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(e) a discussion of learning processes which may help remove them from the domain of the obscure,

(f) some directions that more rigorous analysis of developmental stages might take, and

(g) a simple "rule of thumb" whereby it is possible to identify the most appropriate type of curriculum (e.g., open, behavior modification), given the relative values of desired objectives and the instructional costs associated with various methods of achieving them.

Background

For many years, educational psychology and the application of psychology to education were practically synonymous. Courses in educational psychology consisted of frequently watered down versions of principles adapted from the various sub-specialties of academic psychology. Traditional learning theory rightfully played a predominant role. This circumstance was not so much a result of choice, but of necessity. Indeed, many learning theorists of past decades have realized the inadequacy of their theories with regard to human application. Some, like the late Kenneth Spence, emphasized this point whenever the opportunity arose. Educational psychologists, unfortunately, were only able to choose from among the various competing theories, selecting this one or that, without themselves having anything better to propose.

But times do change. During and after World War II, the urgent need to train personnel to perform complex tasks, and to do so quickly, resulted in the recruitment and involvement of psychologists in designing efficient systems of training. This work continued through the 1950's, and subsequent to increased support for educational research, the movement expanded and was generalized to school learning. Progress during the 1960's was real, and although most of the really complex problems remained unsolved, educational technology began to evolve as a discipline in its own right. It became increasingly clear to all involved that psychology did not have ready made answers which needed only to be applied. Furthermore, the very directions of the research i academic psychology made it unlikely that much of real value would soon be forthcoming.

During this period of the 1960's, "operational objectives," "prerequisites," "hierarchies," "mastery (criterion referenced) testing," and the like became frequent topics of discussion (e.g., Gagne, 1970; Bloom, 1973). Such concepts and techniques were acclaimed by many educators, and widely used in curriculum construction. More recently, however, they have been the subject of increasing criticism. The most valuable educational objectives cannot be operationalized, some have said. Others point out that the approach has led to fragmented curricula. So goes the story.

Some of this criticism, of course, has been at least partially justified and constructive steps have been taken to meet it. To counter arguments concerning the abstract and/or mechanical nature of such curricula, for example, increasing attention has been given to concrete, manipulative experiences in more open classroom settings. Given this milieu, it is natural that many educators, in their search for more adequate conceptualizations, have turned to Piagetian theory and the clinically based research on which it is based. Unfortunately, along with its positive contributions, many have adopted its negative aspects as well. In line with Piaget's early and continued arguments against early S-R behaviorism, for example, many educators have come to feel that <u>any</u> approach to curriculum which involves behavior must be diametrically opposed to current clinical, development-oriented approaches - and more important, that they must be <u>a priori</u> inadequate. It is undoubtedly true that the behavioral objectives and hierarchical approaches to curriculum construction that have been used in the recent past have many limitations - as is true of clinical methods I might add. This is not necessarily true of all operational (behavioral) theories of complex human behavior, however. Some new theoretical developments in structural approaches to learning, for example, may provide a potential basis not only for extending and generalizing the behavioral objectives approach in education but also of providing a rigorous integrated conceptual foundation within which to view all cognition - including cognitive development.

At the present time, I believe, adoption of these deeper and more rigorous conceptualizations has been impeded in part by the general tenor of the times. The activism of the late 1960's for example, has resulted in a general shift in interest from hard science and educational technology to the more social and "humanistic" aspects of educational reform. Recommendations made during this period have ranged from well-intended (and valid, but often rather obvious) warnings that education must be broad based and cannot take place in a social vacuum to high sounding rhetoric and simplistic solutions that have no more scientific validity than alchemy or witchcraft. In effect, the torch was passed for a time from serious scientists to popularizers like Charles Silberman, author of "Crisis in the Classroom." These and other authors of the same ilk have dramatically pointed out shortcomings of our schools, something which unfortunately is all too easy, but have suggested nothing solid to take their place. This is unfortunate because many of the criticisms of educational technology, for example, are based on the false contention that systematic approaches to educational design are inconsistent with more open forms of education. As Glaser (1972) and Resnick (1972) have argued, the very viability of open education over the long term may depend on the further development and intelligent use of educational technology.

Although the process of having to defend educational theory and educational design from such attack has helped to better define problems, it has often tended to detract attention from the process of solving these problems. Indeed, it has sometimes tended to obscure solutions that already exist.

The major purpose of this article is to identify some of the problems that have achieved better definition as a result of this interchange and to indicate how these problems have been solved or might reasonably be attacked. Since I personally tend to seek synthesis in my research, rather than operating in a more eclectic mode, I shall make no pretence of attempting an evenhanded review of the relevant literature. (Unfortunately, this seems today to be a disappearing art in any case.) Rather, I shall restrict myself primarily to those problem areas in which I personally have had a hand. In the process, I shall attempt to emphasize the importance of fundamental and comprehensive theory in solving educational problems.

Some Open Problems in Educational Design

(1) Perhaps the oldest and most basic problem with behavioral approaches to educational design resides in the fact that until recently too little attention has been given to what the learner knows as opposed to what he can do. Specifying only the behavior a child is capable of after learning leaves the "guts" out of learning. Bob Davis[1] illustrates the problem with the child in an individually prescribed learning environment who has learned to place the decimal point in adding numbers according to his own inadequate system. According to Davis, the child responds correctly with problems like ".4 + .3 = .7" and ".2 + .7 = .9". His system works fine here. But, when asked to add "3. + .2," the child responds ".5.".

Not only is it intuitively unsatisfying to limit concern to behavior but it is demonstrably wrong from a theoretical point of view. Given any behavioral objective, if there is one way for the learner to generate the behavior, then there necessarily is an (countably) infinite number of other ways which will also work (Scandura, 1973a). Generally speaking, however, the kinds of knowledge which are consistent with what we might reasonably want the child to know is relatively small. To summarize: Education consists of imparting knowledge (in the broadest sense which includes intellectual and other skills); behavioral objectives provide a means for detecting knowledge but are not equivalent to it.

(2) This leads to a second problem concerning the need for better ways of measuring what it is a person knows. As it has been put by Resnick (1972), there is a need to develop better measures of specific behavioral competencies. Glaser (1973) has gone further and called for the development of a performance test theory. To this I would add that such a theory should provide systematic techniques for constructing tests (cf. Bormuth, 1970). Open education requires not only the availability of good criterion referenced tests, but also methods that the teacher can use to devise tests to meet the needs of unanticipated situations and individuals. The situation is further complicated by the need to utilize more effectively the complementary nature of normative and criterion referenced testing (e.g., Bloom, 1970).

(3) Ideally, "techniques need to be developed for analyzing properties of individual performance frequently enough and in enough detail for individualized instructional decisions (Glaser, 1973, p. 563)." As suggested by DiVesta (1973), we need a deeper understanding of the relationships between objectives and what individuals do and do not know relative to these objectives.

(4) It is not just a question of presenting prerequisites according to a predetermined hierarchy, however. For example, as Resnick (1972, p. 9) has noted, "individuals appear to vary widely in their ability to 'skip' over prerequisites." Why is this so? Can we develop ways of determining ahead of time whether and which prerequisites individuals can skip? Or, better, is it possible for children to learn how to transfer? If so, and this could be tied in with problem solving and "generative skills" (Bruner, 1964), so much the better.

(5) Closely related to the latter, as detailed analysis shows (Scandura, 1973a), are the learning processes by which subject matter content is learned. A major

feature of more open forms of education is that the learner has more control over the manner in which he learns, and indeed in what he does learn. Specifying how the child learns a bit of content, for example, necessarily also specifies the learning process, and hence what process he is apt to learn (better) (e.g., Scandura, 1971 ; Resnick, 1972). If it were possible to analyze learning processes more completely, a good deal of guesswork might be eliminated both in testing for the acquisition of such processes and in learning them.

I have reservations about primarily empirical approaches to the problem. For instance, consider the suggestion that instruction regarding intellectual skills (processes) should begin after prerequisite skills have been mastered and when the developmental curve for the skill to be taught is in a period of transition (Rohwer, 1972). This rule of thumb seems reasonable and in general is probably valid, but I question the feasibility of determining through experimentation separate developmental curves for many such skills, let alone building an entire instructional sequence on this basis. Any viable approach to designing instructional sequences, in my opinion, will necessarily depend on more efficient a priori analyses, and these in turn will have to depend on a deeper theoretical understanding of just what is going on.

(6) In addition to learning processes as isolated entities, are the presumably more general, global systems of knowledge which are assumed to characterize children at various levels of development, systems pertaining, for example, to number, spacial and temporal concepts, general linguistic competence, basic perceptual abilities, and self-motivation. How can such systems be incorporated into an operational instructional system?

Although I believe Piaget to be one of the true all time giants in psychology, I am not convinced that current stage theories provide a sufficient basis for dealing with this problem. Consider, for example, a recent result by Elkind

(1970). He found that "assimilative" practice just before and after the acquisition of a new structure is sometimes so pervasive as to infiltrate unrelated activities during that period, except when the material to be learned does not perfectly "match" the individual's immediate state of cognitive development. Such results are suggestive, especially for the intelligent and gifted teacher who has already observed the phenomenon, but how do you teach the neophyte, or the mediocre teacher what it means, for example, to "perfectly match?"

(7) The above, of course, does not exhaust the list of problems in educational design. Similar concerns have been voiced concerning motivation, attitudes, and social interaction. There are also questions, for example, pertaining to whether instructional sequencing ought to be controlled by the student or by the teacher (e.g., Atkinson, 1972). Proponents of open education tend to favor the former view, whereas traditionalists tend to prefer the latter. While this and many other such questions cannot be answered definitely at the present time, I do believe that answers to the first four questions are presently within sight, and that theoretical means currently exist for dealing with the others.

The Structural Learning Theory

Before confronting these issues directly, let us first review some of the more immediately relevant portions of the structural learning theory (Scandura, 1973a). As those of you who have followed my research over the past decade know, this research has gone through several phases. My initial efforts, centering about my dissertation work at Syracuse, had the rather optimistic goal of understanding the teaching-learning process in its full complexity (e.g., Scandura, 1964). I need not tell you that while some useful leads grew out of this work, my initial efforts were something less than a complete success.

The second phase was spent trying to get a better handle on the problems involved, including the development of suitable research paradigms. This research consisted of a large number of individual studies ranging over a wide variety of phenomena. One major theme of this research was that rules provide a more appropriate basis for analyzing complex human learning than do associations. Rather than viewing rules as complex networks of associations, it was proposed that associations might better be thought of as special degenerate cases of rules (e.g., Scandura, 1967).

The idea of representing competence[2] exclusively in terms of rules (Scandura, 1970, 1973a) appears to be an important one, having been developed independently in computer science (e.g., Minsky and Papert, 1972) and overseas (e.g., Landa, 1973). But, by itself the idea does not go nearly far enough. The structural learning theory is relativistic in nature, being concerned with the observer-subject relationship.

The observer determines what potentially observable behavior is of interest. This behavior, or more exactly, this class of potentially observable input-output pairs, against which actual behavior is to be judged, is predetermined. When the psychologist enters his laboratory, for example, he has a pretty good idea ahead of time what stimuli and what responses he is interested in. Whether or not the subject wiggles in his chair as he elicits the response "MUR" may not only be unanticipated, but typically also will be ignored. Similarly, in testing students to see whether they know the subject matter, the teacher can usually determine in advance what are the stimuli and the corresponding acceptable responses.

The observer, qua competence theorist, also determines how such behavior might reasonably be generated by members of the subject population(s) involved. As in all competence theories (e.g., Nelson, 1968), competence consists of a finite set of rules together with laws governing the way in which these rules may interact in accounting for a given set of elements (in the present case, behavior). What is new in the theory is the idea of allowing rules to operate in a higher order fashion, that is to operate on and to generate new rules. Suppose, for example, that a rule set contains rules for converting from certain English measures of length (yards, feet, inches) to their metric equivalents and no others. According to the structural learning formulation, this rule set would be inadequate for even generating English equivalents of metric measures. The rule set has no provision for rules which operate in reverse direction. The whole situation changes, however, on addition of just one (higher order) rule to the set, a rule which maps English-to-metric rules (e.g., p in. → 2.54 x p cm.) into their inverses (e.g., p cm. → p/2.54 in.). Not only will this inverse rule generate a metric-English rule for every English-metric rule in the set but with the addition of any new conversion rule we get "free" the corresponding inverse.

Allowing rules to operate on rules in this fashion (to generate new rules which in turn can generate behavior) not only provides a great increase in explanatory power, but is consistent with how human beings use the knowledge they have (Scandura, 1973a). Thus, individuals do not need to know explicitly every rule that might be desired. Much of their knowledge is latent in a sense that it can be derived at will when needed from other information which is explicitly available.

In an important sense, the theory directly parallels the situation in which the teacher (whether human or computer) finds itself. The teacher usually knows ahead of time what kinds of behavior it wants the student to learn to elicit. As Glaser (1967) has pointed out, even where objectives appear to be difficult to pin down, as in some forms of open education, this is still a desirable goal to be sought after. In addition, the teacher is usually in a good position to make "intelligent guesses" as to the rules that her students might reasonably be expected to use to generate the desired behavior. Thus, for example, in dealing with subtraction, a group of students which has been exposed only to the borrowing method is not likely to use the equal additions method, which was more popular during an earlier day, or the method of complements which has been widely used in Europe.

In general, in order to devise a competence theory which adequately characterizes a given subject population, an observer must be intimately familiar with their culture and developmental level, and also with whatever subject matters or intellectual processes may be involved. Admittedly, this imposes a heavy responsibility on the observer (theorist) but, if one wants to deal rigorously with the teacher-student relationship, I see no alternative to this. Indeed, significant progress has already been made in this direction (e.g., Carroll, 1973; Newell & Simon, 1972; Scandura, Durnin, Ehrenpreis, & Luger, 1971; Scandura, Durnin & Wulfeck, 1972) and it seems to me to present a fascinating challenge.

So far, notice, nothing has been said about the actual behavior of people. To accomplish this, more structure is added to what we already have. This yields a second level of the theory which deals with human behavior under certain idealized conditions. It is concerned with questions of performance, learning, motication, and, in principle, perception and human development, in situations where the subject is not hampered by memory or by his limited capacity for processing information. In practice this idealization is not as limiting as one might expect.

In the idealized structural learning theory, the term "knowledge" (in contrast with "competence") refers to a potential for behavior. Knowledge also consists of rules, but these rules are attributed to a behaving subject and are thought of as generating behavior. Previous theories (e.g., see Piaget in Furth, 1969) in which rule like constructs are attributed directly to behaving subjects, have been essentially nonoperational. The underlying learning mechanisms have been difficult to test empirically. The Piagetian mechanisms of accomodation and assimilation, for example, are immune in an important sense to behavioral test because the effects of these mechanisms on behavior depend on the knowledge individual subjects have when they enter the learning or testing situation. But, Piagetian theory itself provides no way of finding out what this (individual) knowledge is.

The structural learning theory provides an explicit way of handling this problem. The rules introduced by an observer to account for the behavior of interest are used as an instrument of sorts with which to measure human knowledge. More specifically, the theory tells how, through a finite testing procedure, one can identify which parts of given rules in a competence theory individual subjects know - that is, which rules the subjects can perform in accordance with. The rules in a competence theory in a very real sense serve as rulers of measurement, and provide a basis for the operational definition of human knowledge. It should be noted in this regard that to have behavioral relevance, a rule set must reflect the common culture shared by the population in question.

To briefly review how this is accomplished (for details, see Scandura, 1973a), we first note the basic assumption on which the theory rests is that people are goal directed information processers. Further, rules may be viewed as procedures in the sense of computer programs and may be characterized, for example, as flow diagrams or labeled directed graphs.

INSERT FIGURE 1 ABOUT HERE

Procedures can always be broken down into simple enough steps so that each subject in a given population is able to perform each step perfectly or not at all (cf. Suppes, 1969; Scandura, 1970). In short, each component step of a procedure may be assumed to act in atomic fashion. The behavioral reality of atomic rules has been established, in my opinion, beyond any reasonable doubt (e.g., see Scandura, 1969).

Since each component acts in atomic fashion, each path through a procedure also acts in atomic fashion. That is, each path through a procedure makes it possible to generate responses to a uniquely specified equivalence class of stimulus items, and to no others. Furthermore, there are only a finite number of such paths, since we do not distinguish paths according to the number of repetitions of loops. Collectively, these paths impose a partition on the domain of stimuli to which a procedure applies. This makes it possible to pinpoint through a finite testing procedure exactly what it is that each subject knows relative to the initial procedure introduced by the observer. It is sufficient to test the subject on one item selected randomly from each equivalence class. Success on any one item, according to our assumptions, implies success on any other item drawn from the same equivalence class, and similarly for failure.

Knowledge (behavior potential), then, is also represented in terms of rules (procedures), specifically in terms of sub-portions of initial, corresponding competence procedures. It should be emphasized in this regard that the knowledge attributed to different individuals may vary even though only one rule of competence may be involved. The idea is directly comparable to measuring different distances with the same ruler.[3]

None of this is idle speculation. Scandura (1973a) and Durnin & Scandura (1973) have collected data involving a large number of different tasks, with subjects ranging from pre-school children to Ph.D. candidates. When run under carefully prescribed laboratory conditions, it was possible to predict performance on new items, given performance on initially selected items, with over 96% accuracy. When the testing took place under ordinary classroom conditions, where the subjects were run as a group, the predictions were accurate in about 84% of the cases.

The idealized structural learning theory also provides a precise set of mechanisms by which the rules available to a subject are put to use, and by which new rules are acquired. The basic idea rests on the assumption that human beings are goal directed information processers, and that control shifts among various higher and lower level goals automatically in a fixed, predetermined manner, according to the requirements of the situation.

For present purposes, we may think of the mechanism informally, operating as follows: given a task (stimulus and goal) for which the subject does not have a solution rule immediately available, control is assumed to automatically switch to the higher level goal satisfied by rules which do apply. With the higher level goal in force, the subject presumably selects from among available and relevant higher order rules in the same way as he would with any other goal. In effect, if the subject has an applicable rule available, then he will use it. Where no such higher rules are available, the theory assumes that control moves to still higher level goals. Conversely, once a higher level goal has been satisfied, control is assumed to revert to the next lower level.

Assume, for example, that a subject wants to convert 5 centimeters into inches but that he does not know explicitly a rule for accomplishing this (e.g., he does not know that the required number of inches can be determined by dividing 2.54 into 5). Let us assume, however, that the subject does know a rule for converting inches into centimeters, together with the higher order inverse rule described above. In this case, control would be assumed to shift to the higher level goal of finding a solution rule. According to the simple performance hypothesis, then, the higher order inverse rule would be applied to the inches-to-centimeter rule, generating an inverse rule from centimeters to inches. This newly derived rule satisfies the higher level goal, so control reverts to the original goal. Here the simple performance hypothesis is used once again and the new rule is applied to solve the problem.[4]

Again, none of this is idle speculation. Several experiments (Scandura, 1973a) rather conclusively demonstrate the viability of the analysis, at least under the limited conditions tested. One experiment (Scandura, 1973a), for example, involved simple rules for trading objects such as toothpicks for erasers and a composition higher order rule by which pairs of simple rules (e.g., toothpicks → erasers; erasers → chips) may be combined to form composite rules (e.g., toothpicks → erasers → chips). After training on interpretation of simple rules, naive subjects were either trained or not on the higher order rules. Then, they were presented with new pairs of simple rules and tested on problems that required corresponding composite rules for their solution. Correct predictions in this experiment were made in 29 out of 30 individual cases.[5] In a somewhat more complex and demanding experiment (Scandura, 1973a), each subject was required to generalize from a specific rule. Correct predictions were made in 50 of 50 cases.

The unrestricted third level of the theory deals also with memory and the limited capacity of subjects to process information, but space precludes going into that here. For details see Scandura (1973a).

Resolution of Educational Design Problems

A number of immediate corollaries follow directly from the structural learning theory.

[1] Distinction between behavior and knowledge: Unlike the Piagetian formulation in which the link between theory and observables is often obscure, and unlike the behavioral objectives approach which is essentially devoid of theory (cognition), cognition and behavior are closely tied in newer structural approaches to psychology. In such theories, specifying behavior alone is not sufficient. The knowledge which makes that behavior possible must also be specified.

In this regard, while the precise specification of knowledge (rules) is usually accomplished via some formal algorithmic language, this does not imply that knowledge must be imparted to children in the same manner. The same knowledge can frequently be acquired by telling or by self-discovery, by symbol juggling or by concrete manipulation. Specifying the knowledge underlying concrete manipulations is essentially no different from symbol manipulation procedures such as computational algorithms. Rather than being contrary to Piagetian and other clinical approaches, this approach provides a potential basis for more rigorous analysis of such dynamic situations as those involved in number conservation (e.g., see Scandura, 1972) and other student-teacher interactions (e.g., Witz, 1973). In general, the way in which information is presented to the child depends on factors other than the particular knowledge in question. For example, it may depend on whether the teacher during the course of learning wants the student to also gain experience in discovery.

There are two important points here: (a) If we know precisely what it is that we want a child to learn, then we can facilitate learning far better than if we do not. (b) "Knowing" the subject matter content involved is not equivalent to specifying the relevant knowledge. The former (in b) refers to an intuitive understanding and ability to use the content whereas the latter refers to the ability to describe in some suitable language such understanding and ability.

The difference here between knowing something and being able to describe that knowledge is quite analogous to the difference one might expect between a subject matter expert and a skilled curriculum developer in a subject matter. Indeed, if there is any valid distinction between subject matter educators (e.g., mathematics educators) and subject matter specialists (e.g., mathematicians), and I believe that there is, then it is largely (if not precisely) because subject matter educators must be highly skilled at specifying the knowledge underlying a wide variety of behaviors associated with school learning in the discipline in question.

[2] Assessing behavior potential: Regarding the assessment of behavior potential, little needs to be added to what has already been said. The underlying theory of behavior assessment effectively constitutes a theory of performance testing. Since, in general, any behavioral objective can be algorithmically generated, the methods discussed above can be applied directly to pinpoint

specific strengths and weaknesses relative to each such objective. Furthermore, the paths associated with each procedure can be partially ordered according to difficulty on a priori grounds (Scandura, 1973a). This makes possible sequential testing of items, with correspondingly still further increases in test efficiency (see Durnin & Scandura, 1973).

[3] Relationship between testing and instruction: As we have seen, the algorithmic approach to testing makes it possible to identify precisely not only what the individual learner knows relative to particular procedures (rules), but also what he does not know. A simple basis for instructional decision making follows directly: Teach the learner what he needs to know, and do it in an order compatible with the a priori determined hierarchy of paths.

[4] Transfer - skipping prerequisites: The learning mechanism described above is intended as a general explanation for all transfer and problem solving, not just as an explanation for why some learners are able to skip over certain prerequisites. My comments relative to the latter have recently been published as a note in the Educational Psychologist in the context of a discussion on higher order rules (Scandura, 1973b) and there is no need to repeat this discussion here. Suffice it to say that higher order rules in the sense described above correspond to instructions by which learners may progress from one level in a hierarchy to a higher level (e.g., progressing from a pair of simple rules to a composite rule).

According to this analysis, learners who are able to skip do so because they have already learned a higher order rule by which they can solve the higher level tasks (e.g., those involving composite rules) without instruction. It should be emphasized in this regard that a single higher order rule typically operates in a large class of different hierarchies (and/or between different pairs of levels in the same hierarchy). Indeed, the introduction of higher order rules as in the structural learning theory raises serious questions concerning the very notion of fixed hierarchies (for details, see Scandura, 1973a).

In dealing with the remaining topics I shall have to be sketchy. The above description of the structural learning theory does not deal explicitly with these problems and space limitations make it impossible to even attempt a complete analysis here. What I shall do instead is to indicate sources which deal either in full or in part with these issues together with some general comments which reflect the structural learning point of view.

[5] Learning processes: According to the structural learning theory all learning takes place via the application of existing rules to form new ones.[6] For discussion purposes, of course, it is frequently useful to distinguish between different types of situations in which learning may take place: learning by discovery from one or more instances, learning by exposition, and learning by deduction for example. All of these processes have been analyzed in varying degrees in Scandura (1973a) with respect to the idealized theory. In each case, the proposed mechanism provides a sufficient basis for analysis.

Learning by discovery, for example, involves deriving a rule which satisfies a series of examplars (Ch. 7). In the analysis it is shown that the learner's effective goal changes each time a new exemplar is presented.

Expository learning (Ch. 7) is shown to take place by application of interpretation rules to descriptions (e.g., statements) which generate meanings (e.g., rules). Although examples of expository learning were described, no attempt was made to develop or adapt any existing interpretative grammar for this purpose. Carroll (1973), however, has developed a formal procedure (computer program) for producing sentences given a speaker's intended meaning which (to the extent that interpretation and sentence production involve similar, though reverse, processes) is highly suggestive. In Chapter 5, learning by logical inference is discussed extensively.

In Chapter 10, an enriched mechanism by which information is presumed to be stored in memory, was shown to be compatible with general notions concerning the role of mnemonics in memory (e.g., Bower, 1970; Rowher, 1972).

Although these rather esoteric learning processes can be analyzed in terms of the structural learning theory, it should be emphasized that this alone does not solve the educational problems with respect to these processes. While rule based analyses are possible in principle, and hopefully will become increasingly available through future research, they may not be practicable for some time. In practice, it may be necessary to utilize less sophisticated methods, which nonetheless are compatible with the general approach. Thus, for example, materials were prepared for training teachers in basic learning processes without any serious attempt to detail underlying rules (Scandura, 1971 , Ch. 1). For this purpose, a taxonomy of learning (e.g., discovery) and communicative (e.g., description) processes was proposed along with numerous examples and specific operations (hints) presumably reflective of parts of underlying rules. (Although the ideas were presented in the context of mathematics, they were formulated generally and designed to be applicable to all content areas.)

Direct support for the use of "approximation" methods in training learning processes was found in a recent study by Lowerre and Scandura (1974) on critical reading. In addition to identifying the types of inference rules involved, reading contexts were ordered according to complexity based on a multidimensional scheme designed to reflect possible underlying rules. The viability of the analysis was demonstrated experimentally in the sense that individual capabilities in critical reading were successfully diagnosed and instruction designed specifically to overcome the determined limitations was successful. I suspect that the training methods that Rowher and his associates (1972) used may have been similar to ours in the sense that while Rowher identified a single underlying process, which he called elaboration, his description of the instruction used suggests that it too was based on examples and hints rather than on an explicit underlying procedure.

[6] Global processes: Perhaps the most difficult problem in attempting to utilize stage theories of development in education stems from the Piagetian notion of decalage (e.g., Beilin, 1973; Witz, 1973). As Beilin states, "The issue of so-called horizontal decalage, or generalization across concept domains has been extensively discussed in Piagetian literature, and a number of studies by non-Genevans are addressed to this issue. As the data show, there is both generalization and variability; sometimes variability within a stage takes a consistent form, sometimes not. The issue is a difficult one for stage theory and investigations sympathetic and unsympathetic to stage theory will be dealing with it for a long time." This state of affairs suggests that while developmental stages may be suggestive regarding education, they are not sufficiently developed to provide anything close to an adequate basis for making instructional decisions regarding individual children in specific situations.

It is my belief, although I have not had time to work on the problem seriously, that such phenomena as horizontal decalage can be analyzed in structural learning terms. Thus, for example, a child who conserves number but has not yet learned to conserve length (or vice versa) would be postulated not to have available a higher order rule by which linear distances can be generated from numbers (or vice versa). Conversely, a child who not only conserves in both domains, but also can solve a more or less broad range of analogous problems involving length (given experience with corresponding tasks involving number), would be presumed to have learned some such higher order rule. I know of no research which bears directly on this issue but some ought to be done.

In this regard, I should like to put to rest another common misconception regarding higher order rules. Since all learning takes place by application of higher order rules, the question arises as to where the higher order rules come from in the first place. Do they come wired in? My answer is both yes and no.

In common with certain innatists (e.g., Chomsky, 1968), I do believe that the infant has certain innate capabilities and basic behavioral tendencies (instincts) at birth which provide a foundation for future learning. But, no! I do not believe that he enters the world with anything approaching the kinds of complex higher order rules identified, for example, in our analysis of geometry construction problems (Scandura, Durnin & Wulfeck, 1972).

The resolution of this apparent paradox follows from two basic facts: (a) In the theory, the descriptor "higher order" refers not to the rule itself but to the use to which it is being put. That is, no distinction is made between rules as rules. A rule is given the descriptor "higher order" when it is acting on another rule as in satisfying a higher level goal. In other situations, this same rule may act directly, thereby acting as a lower level rule (for details, see Scandura, 1973a). In computer science, this type of classification according to use is referred to as "unstratified" control (Gorn, 1968).

(b) Analysis with respect to any given domain of tasks may be continued any number of levels. Thus, a rule set which accounts for a given class of tasks may be further analyzed in the sense that one can identify a still more basic set of rules (including more basic higher order rules) from which that rule set may be derived. In general, the further that an analysis is extended in this way to more basic rule sets, the simpler the constituent rules become. Ultimately, although this has not been demonstrated explicitly, the rules presumably become so simple as to correspond directly to the kind of instincts infants are presumed to have.

In Scandura (1973a), basic rule sets of this sort were called "innate bases" for other rule sets in the sense that they could, by interacting with the environment, "grow" to generate all of the rules in the latter (plus additional ones of its own). A direct corollary of the theoretical analysis presented there was that the finer grained (i.e., more basic) the initial capabilities with which an organism is born, the greater its intellectual potential. Although this is not the place to get into this matter, the analysis is highly compatible with a number of well known cross and within species developmental findings. Thus, for example, humans enter the world with far less in the way of sophisticated capabilities, as compared, say, to the great apes, but they eventually not only catch up but surpass them intellectually. Similar results within the human species itself, while not as dramatic, and more limited to particular task domains (e.g., spatial visualization and the ability to verbalize) might well be analyzed in the same general way.

[7] Although there are many important educational problems with which we have not dealt, hopefully enough examples have been presented to indicate the theory's potential breadth of application. At the present time we are planning a comprehensive attack on the problem of optimizing instructional sequences with respect to realistic curricula. The work has not progressed far enough for presentation here, but a preliminary summary of my thinking may be of some interest.

At a conceptual level it is fairly apparent how the structural learning theory provides a basis for conceptualizing the teaching-learning process. In outline form the idea is as follows. The learner has certain knowledge (rule sets) at his command on entering into the teaching situation. Additional learning takes place by interacting with the teaching environment according to mechanisms specified in the theory. In general, what is learned at each stage depends both on what is presented to the learner and what he knows. The changes from stage to stage are cumulative.

In order to talk about the optimization of instruction, two additional things must be done. First, educational objectives must be identified, and values assigned to them. For present purposes, we can think of the objectives as behavioral objectives with the proviso that objectives corresponding to higher order rules are included. Clearly, individual objectives may vary in importance depending upon what the teacher or curriculum constructor values most. Weights are assigned to the various objectives to reflect these values.

The second idea concerns the various costs of instruction. Time required for instruction would seem to provide one natural measure.

The optimization of instruction, then, consists of finding an optimal trade-off between the sum of the values of the objectives achieved and the total time required for instruction. It will frequently be the case, for example, that the instructional costs involved in achieving a highly valued objective are apt to be relatively high. Optimization involves balancing gains against costs - a type of cost-benefit analysis.

Without attempting to enter into the type of intensive analysis of this problem that is envisioned, some sense of its potential can be seen from the following. Suppose we have general information concerning the relative values assigned to various objectives of a curriculum and the relative costs of various instructional methods that might be used. What we want is a "rule-of-thumb" for specifying the type of curriculum best suited to our needs.

In general, the assignment of values to objectives will vary as to homogeneity. The possibilities range from giving high value to relatively few objectives, with low value to the others, to moderate value over a broad range of objectives. At the one extreme, for example, high value might be placed on computational skill in arithmetic, with little concern for meaning, while at the other extreme, a broad range of arithmetic abilities might be given equal weight. In the figure below, at the risk of oversimplification, the possible assignments of values between these extremes is represented by a single dimension.

Instructional time costs are similarly represented. In this case, the dimension ranges from high costs for all but a few kinds of instruction to more evenly moderate costs for a broader range of instructional forms. Thus, for example, at one extreme, circumstances might require specific, teacher directed instruction because of the relatively high costs of other forms. At the other extreme, a broad range of possibilities, as in learner directed instruction, might be equally viable. (These dimensions would lend themselves quite naturally to information-theoretic measures.)

INSERT FIGURE 2 ABOUT HERE

For illustrative purposes, a number of typical curriculum forms are plotted in Figure 2. Although one should not take the exact placement of these types too seriously, their classification does show how arbitrary curriculum forms may be viewed in these terms. For example, the Summerhill school, which is well-known for its broad-based, permissive atmosphere, is placed at the lower right. In contrast, military training, with its high premium on the efficient acquisition of certain skills, is placed in the upper left. To summarize, the effectiveness of various types of curricula depends on the values assigned to possible educational objectives and the costs (or availability) of various kinds of instruction. The open classroom, for example, is a suitable form of instruction, but only where there is a reasonably broad range of desired objectives and largely equivalent costs for various forms of instruction.

Let me conclude with a statement of faith, arising from my own experiences. In common with most educational psychologists, I do not believe rhetoric to be the answer to educational problems, and in common with some (e.g., Rothkopf, 1973), I do not believe that sheer volumes of empirical research will do either. Rather, I believe in common with what I sense to be a growing core of individuals (e.g., DiVesta, 1973) that our greatest need is fundamental theory tailored to the needs of education. To my mind, this means a theory which integrates content and individual behavior into a unified system and in which both the observer (teacher) and the subject (learner) play an integral role. Finally, I believe that to be maximally useful, we need a strong, operational theory which is sufficiently precise to lead to empirically falsifiable hypotheses. The structural learning theory appears to have these characteristics and offers a chance of capturing the essentials of the instructional process.

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Footnotes

1. Personal communication.

2. A distinction between competence and knowledge is made below.

3. Even though knowledge is always defined in terms of the rules in a predetermined competence theory, it must not be thought that such knowledge is arbitrary. If two or more rules of competence each provide a consistent basis for assessing behavior potential (i.e., if performance on the respective equivalence classes is homogeneous), then the respective (sub)rules used to characterize knowledge are necessarily equivalent. Furthermore, any viable competence theory in this view must be capable of withstanding behavioral test (Scandura, 1973a). Competence and knowledge are analogous to the chicken and the egg insofar as priority is concerned.

4. In actuality, this mechanism is oversimplified. For details concerning an enriched mechanism which deals with rule selection (where two or more rules apply), and which allows for false starts(i.e., backtracking), see Scandura, 1973a, Ch. 9.

5. There was reason to believe in the one deviant case that the conditions of the experiment had not been adequately fulfilled. The subject was run through the same experiment a week later, using different rules, this time with positive results.

6. It should be noted that knowledge may include elements which do not act on other elements. Such elements correspond to specific items or facts (e.g., the numeral "5," the fact "John is married to Sally"). At a formal level such facts, when treated simply as a type of degenerate rule, obey the same laws as other rules.

FIGURE 1

Sample

Stimuli---> Responses

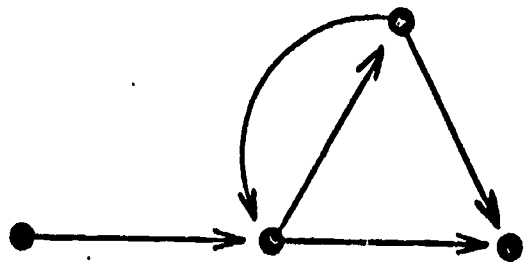
101---> 102

12---> 20

2---> 10

222---> 1000

Total Graph



Paths (Subgraphs)

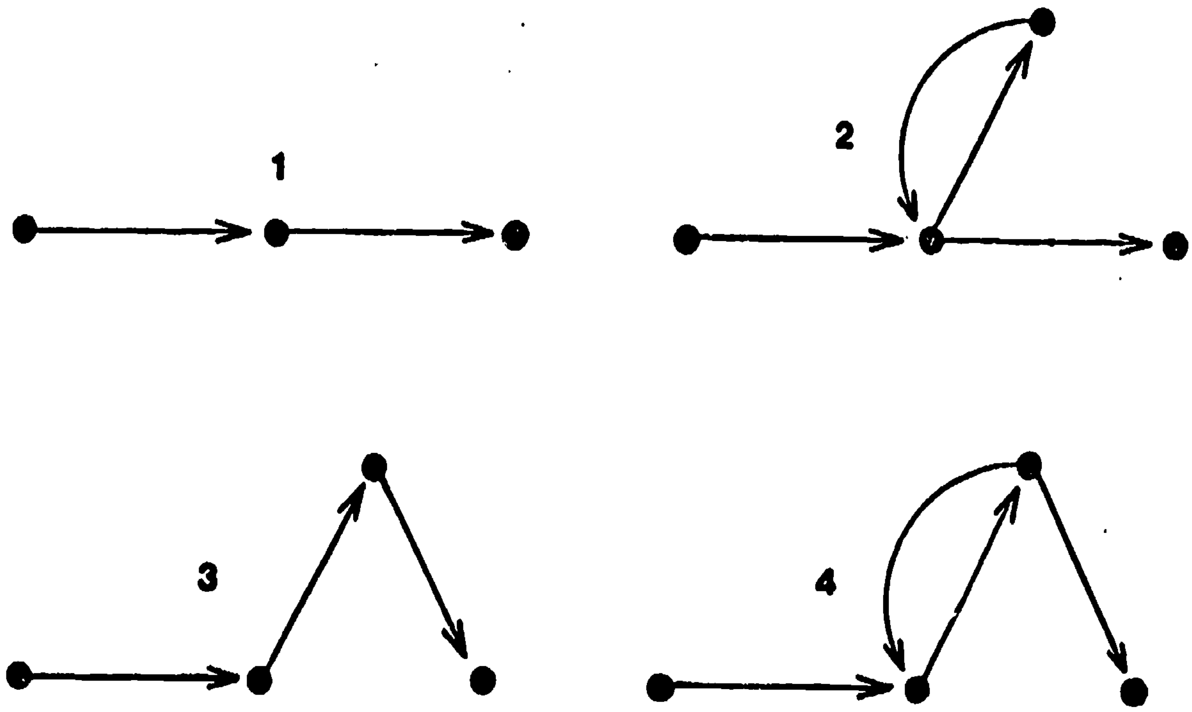
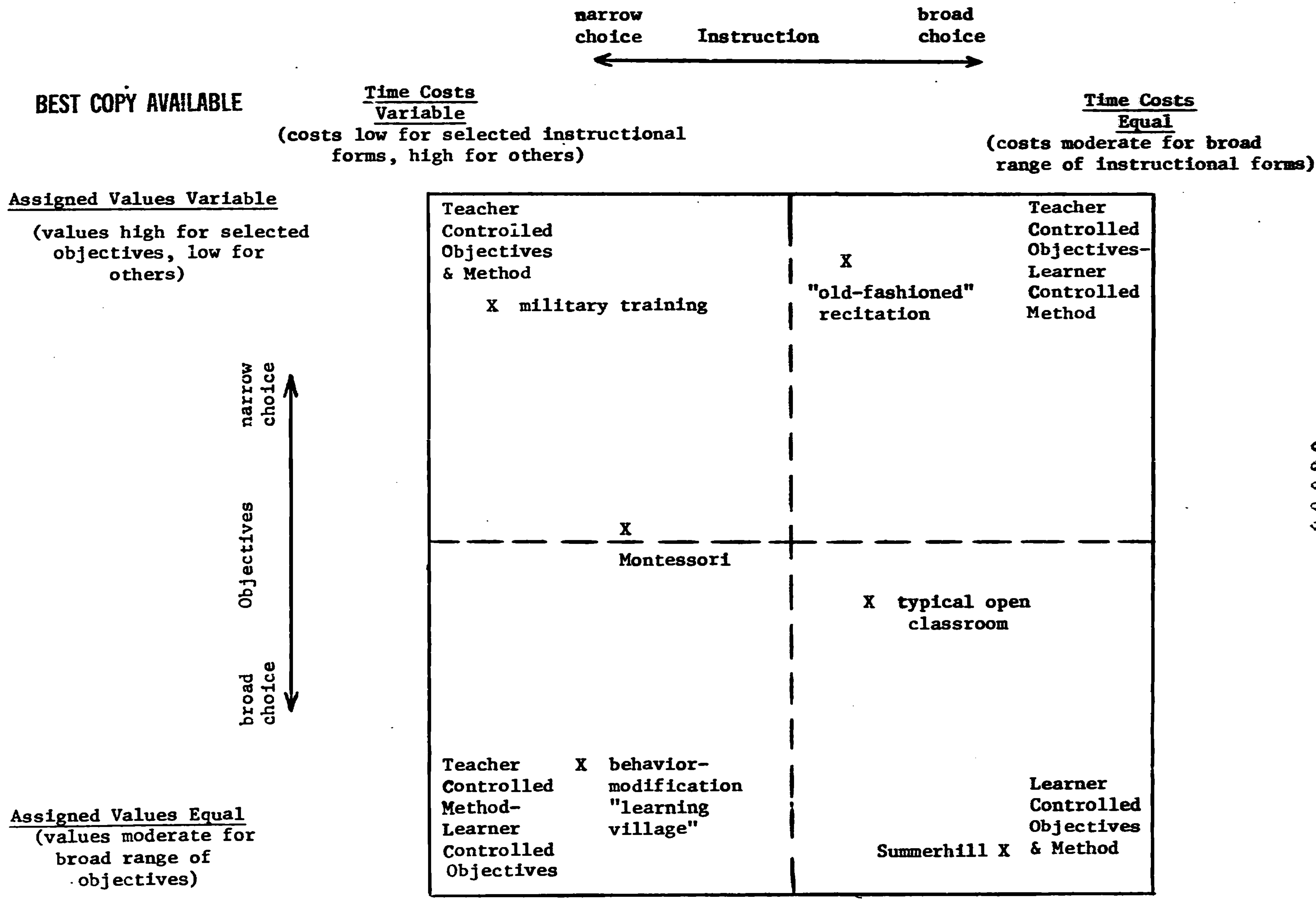


FIGURE 2


narrow choice
Instruction
broad choice
Time Costs Variable
(costs low for selected instructional forms, high for others)
Time Costs Equal
(costs moderate for broad range of instructional forms)
Assigned Values Variable
(values high for selected objectives, low for others)
Assigned Values Equal
(values moderate for broad range of objectives)
narrow choice
Objectives
broad choice
Teacher Controlled Objectives & Method
X military training
X "old-fashioned" recitation
Teacher Controlled Objectives-Learner Controlled Method
X
Montessori
X typical open classroom
Teacher Controlled Method-Learner Controlled Objectives
X behavior-modification "learning village"
Summerhill X
Learner Controlled Objectives & Method