motor-sensory interactions in learning, by showing that learning arrangements which involve response control of stimulus or sensory processes (however signalled or instructed to an animal or individual) demand near-immediate sensory feedback from the movement for effective performance and learning. In contrast, in loose, uncontrolled conditions of delayed rewarded performance, punished performance or only general knowledge of results of performance, in which primary motor-sensory circuits operate without knowledge of experimenters or teachers, the temporal delay factors related to the open-loop after-effects are not critical (Hull, 1943).

The delayed feedback experiment defines other critical motor-sensory time factors in performance, learning and educational technology besides the general factor of delay. There are many possible conditions of dynamic and static sensory feedback related to the delayed feedback of response. Dynamic feedback is the continuous sensory feedback defined by the temporal characteristics of specific movements as sensed directly by kinesthetic, tactual or other channels, or in terms of the continuous effects of these movements on the environment.

References


Instructal Development Articles

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Structural Approach to Behavioral Objectives and Criterion-Referenced Testing

Joseph M. Scandura

In recent years, important advances have been made in understanding the theoretical foundations of teaching and learning. Particularly noteworthy in this regard are structural, systems and cybernetic approaches to the problem.

Although working independently, a number of structural theorists have come from somewhat different directions to compatible and in some cases similar conclusions. The works of the English cyberneticist-engineer Pask (1975) and myself (1973a), for example, share a number of important features, although the scientific languages used and the specific mechanisms differ considerably (cf. Pask, 1975, p. 304; Scandura, 1976a). The independent work of Landa (1974) in Moscow is also compatible although the emphasis here is not so much with theory as with the use of algorithms as a scientific language for describing various aspects of teaching and learning. In this sense, it is a close scientific cousin to the “set function language” (Scandura, 1967, 1968).

In contrast with the scientific “world views,” which these alternative conceptions represent, the purpose of this article is very modest indeed. I shall attempt to show in straightforward, concrete terms how my own theory of structural learning might be applied in instructional design.*

Toward this end, I shall deal only with the problems of behavioral objectives and criterion-referenced testing, and specifically with how the

*The reader should not infer that what follows adequately describes the structural learning theory. In truth, it says almost nothing about the theory per se. It deals exclusively with implications that the theory has for operational objectives and criterion-referenced testing.

Joseph M. Scandura is with the MERGE Research Institute, affiliated with the University of Pennsylvania, Philadelphia.

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concerns which each represents can be dealt with more precisely (and usefully) within the structural learning framework. In the process, I shall outline the major ingredients for a cognitively based performance test theory and show how that theory might be applied in the real world both for diagnostic and instructional purposes.*

The Structural Approach to Behavioral Objectives

As is well known, specifying objectives in behavioral terms tells what it is that the learner must be able to do as a result of learning. The term “knowledge,” on the other hand, is used in structural learning theory to denote a rule (procedure/algorithm/relationa net) construct which reflects a potential for behavior.

Perhaps the most basic inadequacy of traditional behavioral approaches to education is that specifying behavioral objectives does not tell what the learner must learn or what the teacher must teach. Specifying only behavioral objectives themselves leaves the “guts” out of learning. For example, consider an observation (personal communication) made in an individually prescribed learning environment by Bob Davis, a well-known innovator in mathematics education. Davis became interested in a child who had learned to place the decimal point in adding numbers according to his own system. Given “.4 + .3”, for example, the child would respond “.7”. Similarly, he could correctly add “.2 + .7”. His system works fine where the decimal point is to the left. But, when asked to add “3. + .2”, for instance, the child would respond “.5.”

Why? Not surprisingly, answering this question requires more than knowing the behavior to be expected in adding decimals. It is necessary also to specify what a person must know (competence) in order to add decimals. In particular, in the above example, one must specify what rule would lead a child to respond correctly to the first two instances and incorrectly to the third.

To argue that the behavioral objective observed by Davis may have been poorly formulated would miss the main point. Specifying underlying competence is important for several reasons: (1) Given any class of tasks (e.g., a behavioral objective), if there is one rule that will generate a solution for each task, then there are any number (countably infinite) of other rules that will do the same thing. (This is a mathematical fact which can be easily proven.) (2) In practice there is often more than one feasible rule for generating behavior associated with a behavioral objective. Which rules are feasible depends on the “culture” in question. Borrowing, for example, is the preferred method of teaching subtraction in American schools, whereas in German schools the method of equal additions is used. (3) The selection of one or another (or all) feasible rule(s) has important and direct implications for instruction. (As we shall see in the next section, it also has direct implications for performance testing.)

In teaching logical reasoning in reading (e.g., Lowerre and Scandura, 1973), for example, it is possible to emphasize syntax (e.g., all A are B, x is an A; therefore x is a B) and/or semantics (e.g., Venn diagrams). Whereas syntactic rules of inference are adequate within their assigned domains, there is little basis for positive transfer to other inference rules, as is the case with inference rules based on meaning. In the latter case only, the process (e.g., using Venn diagrams) by which one combines meanings of individual premises and checks to see if conclusions follow from them are the same irrespective of the particular inference rules involved (see Scandura, 1977b, Chapter 12; for a more general but analogous treatment see Scandura, 1971b, Chapter 3).

In short, unlike behavioral objectives qua behavior objectives, which are devoid of underlying competence, competence and behavior are intimately tied together in the structural learning theory—indeed, in most of the newer structural-algorithmic approaches to education (e.g., Gagne, 1970; Landa, 1974; Pask, 1975).Specifying behavior alone is not sufficient; the competence (rules) which makes that behavior possible must also be specified.

To minimize misinterpretation of the intended scope, or applicability, of the rule construct, three cautions seem in order.

1. Although the precise specification of competence in terms of rules is usually accomplished via some formal, relatively low level (i.e., detailed) algorithmic language, this does not mean that rules necessarily must be represented with this precision or in this degree of detail. Thus, whereas rules (procedures/algorithms) in computer programming

*The interested reader is referred to Scandura (1972, 1973a, 1973b, 1976b) for an introduction to the theory. The books on structural learning (Scandura, 1973a, 1976b) provide a thorough and quasi-formal treatment of the theory and research up to about 1972. The most up to date version of the theory, including several important generalizations and refinements, especially involving the theory of teaching and learning, are available in Scandura (1977a, 1977b). For an early precursor of the theory, the historically oriented reader is referred to Scandura (1964).
are typically represented in terms of fixed computer languages, the linguistic elements used to represent rules of human competence/knowledge are more varied. Specifically, the units (operations and decisions) of which knowledge rules are constructed, and correspondingly the linguistic elements used to represent these units, vary in scope according to the intended population of human information processors. The more sophisticated the population, in general the larger and more varied are the linguistic elements that can properly be understood (as units). In turn, the larger and more varied the units, the easier it is to represent competence. It is this characteristic flexibility that leads to the broad applicability of structural representations, including applicability to what initially might appear to be intractable tasks.

Consider, for example, the ability to read critically—that is, the ability to detect logical (or other) relationships among statements in a paragraph. It would be difficult indeed to detail all of the operations and decisions involved in encoding and interpreting individual morphemes as well as in determining grammatical and logical interrelationships. However, given that students can properly understand individual statements, the task becomes much easier. The individual meanings, for example, can be represented as regions in Venn diagrams and the interrelationships as set membership, intersections, unions and complements of such regions (e.g., see Scandura, 1977b, Chapter 12; Scandura, 1971b, Chapter 3).

2. The representation of competence in terms of rules is quite independent of how competence is to be imparted to children. The same competence frequently can be acquired by telling or by self-discovery, by symbol juggling or by concrete manipulation. In general, the way in which information is presented to the child depends on factors other than the particular competence in question. For example, it may depend on whether the teacher during the course of learning wants the student also to gain experience in discovery (and thereby to learn how to make discoveries in related situations; Scandura, 1971a, 1973a). The main point is that if one knows precisely what it is that one wants a child to learn (and not just the behavior the child is to evidence as a result of learning), then one can facilitate learning far better than if one does not.

3. “Knowing” the subject matter content involved is not equivalent to specifying the relevant competence. The former refers to an intuitive understanding and ability to use the content, whereas the latter refers to the ability to suitably describe or illustrate such understanding and ability. This distinction between knowing something and describing that competence is analogous to that, for example, between being able to solve mathematical problems and being able to tell someone else how to solve them.

It would appear, in summary, that specifying behavioral objectives is not equivalent to specifying underlying competence. The former tells only what the learner is supposed to be able to do; the latter tells, in addition, what the learner must know or learn in order to do it. Moreover, there is an important difference between specifying competence so that humans can understand it and specifying competence in a form that can be interpreted by computers. In the former case, competence is specified in terms of units at whatever level is appropriate to the target population. In the latter case, competence is specified at a fixed level of analysis. In the next section, we shall see the level of representation also has important implications for performance testing.

The Structural Approach to Criterion-Referenced Testing

Let me now turn to the widely recognized need for better measures of specific behavioral competencies (e.g., see Resnick, 1972), and especially for better measures based on a sound theory of performance testing (e.g., see Glaser, 1973).

Mastery testing (e.g., Bloom, 1973) represents an important advance over normative testing in so far as instruction is concerned. It provides information not only concerning the relative capabilities of two or more testees but also concerning the specific capabilities of individuals. Criterion-referenced testing represents a refinement of mastery testing in which the conditions of testing and of mastery are defined more precisely. The introduction of item forms into criterion-referenced testing by Hively and his collaborators (e.g., Hively, Patterson and Page, 1969) goes further in this direction, as does their later development at Pittsburgh (e.g., Ferguson, 1969). Item forms make it possible with paper-and-pencil tests to pinpoint, more precisely than in simple criterion-referenced testing, just what kinds of items within a given task domain a person can deal with effectively and what kinds he cannot.

None of the above forms of criterion-referenced testing, however, deal with the relationship between behavior and competence. The structural learning theory (Scandura, 1971a, 1973a), on the other hand, provides an explicit way of dealing with this relationship. Specifically, rules of competence introduced to account for performance on given behavioral objectives provide an instrument
of sorts with which to measure human knowledge. The theory tells how, through a finite testing procedure, one can identify which parts of to-be-taught rules individual subjects know. The rules in a very real sense serve as rules of measurement, and provide a basis for the operational definition of human knowledge.

Let us briefly consider how this may be accomplished (for details, see Scandura, 1973a; Durnin and Scandura, 1973). The flow diagram in Figure 1 depicts a rule (procedure/algorithm) for subtracting numbers. This rule is broken down into steps that are so simple that each individual subject may be assumed able to perform either perfectly on each step or not at all. We say that each component step acts in an atomic fashion (i.e., acts as a unit). In line with the above discussion, it is worth emphasizing that what are atomic units relative to one population may not be atomic units with respect to another (e.g., less sophisticated) population.

Because success on any path of a procedure depends on success on all atomic components, each path through the procedure also acts in atomic fashion. Furthermore, there are only a finite number of behaviorally distinct paths. We do not distinguish paths according to the number of repetitions of loops because the same cognitive operations and decisions are required regardless of how many times a given loop is traversed in carrying out a given "cognitive computation."

Collectively, the paths of the subtraction rule impose a partition on the domain of column subtraction problems; that is, they define a set of distinct, exhaustive and homogeneous equivalence classes of subtraction problems such that each problem in any given class can be solved via exactly one of the paths.

One path through the subtraction algorithm is represented schematically in Figure 2, along with two column subtraction problems to which the path applies. Notice that operation (arrow) 1 says to go to the rightmost column. The second node asks whether the top number is greater than the bottom number. (The first node = START.) Since the answer is yes, operation 2 is applied (i.e., the bottom number is subtracted from the top number). Next (node three), we ask if there are any more columns. If there are, we proceed to the next column (operation 3) and repeat. Otherwise we stop.

The fact that each path is associated with a unique subclass of column subtraction problems makes it possible to pinpoint through a finite testing procedure exactly what it is that each subject knows relative to the initial rule. It is
sufficient for this purpose to test each subject on one item selected randomly from each subclass. Success on that item, according to our assumptions, implies success on any other item drawn from the same equivalence class, and similarly for failure.

Individual knowledge (or behavior potential), then, may also be represented in terms of rules—specifically, in terms of subrules of the given rules of competence. The knowledge attributed to different individuals, however, may vary even where only one rule of competence is used to assess behavior potential. For example, suppose a subject succeeds on only one path, and fails on the others. Then, his knowledge would be represented by that path (which is a subrule of the initial one). Where two or more paths are involved, a combination of the paths would be used to represent the knowledge.

Fortunately, the above discussion is not just a theoretical exercise. Although the variety of task domains considered is limited, a relatively large amount of supporting data has been collected over the past several years with subjects ranging from preschool children to Ph.D. candidates. Given a class of tasks, the general form of each study was as follows: (1) Rules were identified which were both adequate for generating solutions to each of the tasks and compatible with the way a knowledgeable/idealized member of the target population might be expected to solve them. (2) These algorithms singly and/or collectively were used to partition the class of tasks into equivalence classes. (3) Students-subjects in the target population were tested on two items (tasks) from each equivalence class (and item form). (4) Performance on one item from each equivalence class (item form) was used as a basis for predicting success or failure on the other (second) item.

With highly structured tasks, run under carefully prescribed laboratory conditions, it has been possible to predict performance on new (second) items—given successful performance on initial items, with over 96 percent accuracy (Scandura, 1973a; Scandura and Durnin, 1977). When testing took place under ordinary classroom conditions, with the subjects run as a group, the predictions were accurate in about 84 percent of the cases (Durnin and Scandura, 1973).

In this latter case, the equivalence classes determined via the structural/algorithmic approach were compared with item forms identified by Hively et al., (1968) and Ferguson (1969). Whereas the levels of prediction on success items were approximately the same, the algorithmic/structural approach was significantly better in predicting failures. Equally important, this level of prediction was obtained with half as many test items—with an even greater increase in efficiency possible through the use of conditional testing (Durnin and Scandura, 1973).

Moreover, the use of item forms has been limited to paper-and-pencil tests. As noted by Gagne in an unpublished APA talk in 1975, they have intrinsic limitations with regard to non-paper-and-pencil applications such as job analysis. The structural approach is not limited in this way. The direct relationship between size of atomic rules and sophistication of population allows for broader applicability. In job analysis, for example, it would make little sense to attempt a molecular analysis of arithmetic skills in order to judge accounting skills, or of writing syntax in evaluating professorial capabilities. Although the impatient reader may have some doubts, minimal capabilities can reasonably be assumed of all bona fide professionals. Thus, all trained accountants presumably can add a column of figures, and all experienced Ph.D.'s have at least minimal writing capabilities. Hence, it is sufficient to consider only those more competencies (atomic rules) that distinguish among individuals in the target population—for example, the ability to set up and administer efficient accounting systems for companies of various types.

There is one further major advantage of the structural approach to assessing behavior potential: It fills an important need in making individualized instructional decisions. Quoting Glaser, “techniques need to be developed for analyzing properties of individual performance frequently enough and in enough detail for individualized instruction decisions (1973, p. 563).” Or, 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.”

It is clear from our examples that the algorithmic/structural approach makes it possible to identify precisely not only what individuals can and cannot do, as is the case with item forms, but also what the learner does and does not know relative to the particular rules involved. A simple basis for instructional decision-making follows directly: Assume the paths the learner already knows, and concentrate on those that he/she does not.

Summary
In summary, it would appear that any viable theory of performance testing must take into account underlying competence. Rules of competence associated with populations of subjects not only provide a basis for measuring individual knowledge and for providing remedial instruction but also for selecting appropriate test items.
Furthermore, since the appropriate level of rule representation varies directly with population sophistication, it is often practicable to analyze even complex task domains (at a level of analysis that is sufficient for assessing the behavior potential of individuals in the population).

The interested reader is referred to the literature for information regarding the consolidation of knowledge (Scandura, 1977b), hierarchal relationships among paths and the conditional testing this makes possible (Durnin and Scandura, 1973; Scandura, 1973a), and the use of sets of rules for assessment purposes (Scandura, 1977b).

References


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