INSTRUCTIONAL THEORY

Any viable theory of teaching and learning must include, first, some way of specifying what must be learned, or equivalently some way to represent competence. Second, it must elucidate the processes by which people use, acquire, and modify their existing knowledge. Third, there must be some way to find out what individuals know at any given stage of learning, including a way to determine their initial knowledge. Fourth, a fully adequate theory of teaching and learning must allow for the growth of knowledge over time, as learners interact dynamically with a changing teaching environment. Finally, the theory must work: to cite Kurt Lewin’s dictum: there is nothing so practical as a good theory. This entry will show how contemporary instructional theory (Scarduna, 1980) may be used in designing effective and efficient instruction.

INSTRUCTIONAL STRATEGY

The essential first step in designing instruction is to identify: (1) the educational goals: what the learner is to be able to do after instruction; and (2) prototypic cognitive processes or rules: what the learner must learn so as to perform successfully on tasks associated with the educational goals (Scarduna, 1971). Thus for example, educational goals may vary at one extreme from something as specific as saying “cat” when shown a cat, to something as broad as being able to devise an operational theory to explain any given set of behavioral phenomena. (In this regard, it is not essential to specify each and every criterion task, but only to be able to distinguish given tasks that qualify from those that do not. Note also that prototypic processes may be specified by the teacher or via behavioral research.)

In structural learning theories what must be learned is one or more rules. In such theories, rules are theoretical constructs used to represent all kinds of human knowledge. A rule consists of a domain or set of encoded inputs to which it applies, a range or set of undecoded outputs which it is expected to generate, and a restricted type of procedure which applies to elements in the domain.

For example, consider a rule for adding ed to verbs. In this case, the domain of the rule is the set of all verbs to which ed can be added. The range of the rule consists of the resultant verbs (i.e., the verbs with ed added, properly spelled). The procedure of the rule may be described as follows:

1. If the last letter (of the verb) is a c, add a k and then ed.
2. Otherwise, if the last three letters are of the form consonant-vowel-consonant, double the final consonant and add ed.
3. Otherwise, if the verb ends in e, just add d.
4. Otherwise, if the last letter is y preceded by a consonant, change y to i and add ed.
5. Otherwise, just add ed.

Structural learning theory provides a general method of analysis, called structural analysis, by which the rules to be learned can be derived from suitably operationalized educational goals. The first step involves selecting a representative sample of problems associated with the educational goal in question. In the case of simple subtraction, this sample might include such problems as:

<table>
<thead>
<tr>
<th>9</th>
<th>879</th>
<th>432</th>
<th>402</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
<td>-325</td>
<td>-129</td>
<td>-129</td>
</tr>
<tr>
<td>?</td>
<td>??</td>
<td>??</td>
<td>??</td>
</tr>
</tbody>
</table>

The second step involves determining the scope of each selected problem and identifying rules for solving each type. Identifying such rules involves several identifiable substeps:

1. Assumptions must be made regarding the minimal encoding and decoding capabilities of the students in the target population. In the case of second graders, for example, the teacher/analyst would normally assume that all students are able to distinguish the minus sign, the individual digits 0,1, . . . , 9, the columns, and the rows, and that all are able to write the individual digits in desired locations. The remainder of any analysis will be adequate just to the extent that these assumptions are applicable to individual students in any given target population.
2. The analyst must decide the scope of each of the sample (prototypic) problems. This scope effectively defines the domain of the rule associated with each prototype. The problem

\[
\begin{array}{c}
432 \\
-129 \\
\text{???}
\end{array}
\]

for example, might be held prototypic of the entire class of column subtraction problems, namely those formed by varying the individual digits 0, 1, . . . , 9 and/or the number of columns. Indeed, in the present case, each of the selected representative problems is prototypic of this same domain. Consequently, in the present case, it is reasonable to assume that there is only one domain, the domain of column subtraction problems.

3. Next, the analyst must identify the cognitive steps (operations and decisions) involved in solving each of the representative problems. These operations and decisions must be sufficiently simple that using them refers only to encoding/decoding abilities that are assumed to be available to all in the target population. The operations also must be atomic in the sense that, for each student in the target population, correct use of an operation once is indicative of uniform success, and incorrect use, of failure.

The flow diagram in Figure 1 depicts the procedural portion of a rule based on borrowing, more commonly known as the “borrowing algorithm.” Notice that each operation of this procedure acts on digits, rows, and columns, illustrating the need to assume certain minimal encoding/decoding abilities. The decisions of this procedure (e.g., Is top number greater than or equal to bottom number?) constitute additional assumptions concerning minimal cognitive ability. In turn, the operations (e.g., change 0 to 9, subtract using basic facts) must be either known perfectly or not at all. According to structural learning theory, only to the extent that these assumptions are met will this subtraction rule provide a useful and operationally precise basis for designing efficient and effective instructional strategies.

Much more can be said about the actual processes by which rules are constructed, but this area is currently the focus of considerable research and going into it here would detract from the main concerns. The essential is that the use of structural learning theories for purposes of designing instruction necessarily begins with a structural analysis of the subject matter in question. Notice, in particular, that nothing is said about a taxonomy of subject matter content; unlike taxonomic approaches to instructional design (Gagne, 1965), all content according to the structural learning perspective must be analyzed.

INSTRUCTIONAL STRATEGIES

Once a structural analysis has been completed, designing an effective instructional strategy follows directly and precisely from the theory. Specifically, once an analysis has been completed, one knows (1) what the student is to be able to do upon achieving the educational objectives (e.g., solve arbitrary column subtraction problems), and (2) what the student must consequently learn (i.e., the entire borrowing rule).

Given this information, the first thing one must do in designing an effective instructional strategy is to determine what each student already knows—specifically, which parts of the rules must be learned. The testing process by which this is accomplished has been detailed elsewhere (Scandura, 1971, 1977) and is not considered here. For present purposes it is sufficient to observe that solving particular subtraction problems involves following one and only one path through the subtraction rule. In effect, there is a unique class of problems associated with each path through

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Figure 1. Procedure for subtraction rule based on borrowing. Adapted from Figure 2 in J. M. Scandura, Problem solving (New York: Academic Press, 1977). Printed with the author’s permission.
the rule, and there are only a finite number of different paths associated with any given rule.

Moreover given the above assumption of atomicity (of basic operations and decisions), success or failure on any one problem associated with such a class provides complete information as to the availability to the student of the particular path in question. For example, the problem

\[
\begin{align*}
879 \\
-325 \\
???
\end{align*}
\]

is solved by following the path defined by operation one, then two, then three, and back to two, before stopping.

By testing on a small, finite set of problems, it is possible to identify precisely and unambiguously which parts of the subtraction rule any given individual knows and which parts he or she does not know. Such testing, in effect, defines the student's entering level. It is sufficient for this purpose to test each subject on one randomly selected item from each equivalence class, for according to the atomicity assumptions, success on any item implies potential success on all other items from the same equivalence class. By capitalizing on hierarchical relationships, sequential testing may require even fewer test items.

Prescribing instruction, then, follows directly from what the student knows. All one need do is identify the missing portions of the desired subtraction rule and present them to the student. For example, suppose a student's knowledge may be represented by the flow diagram shown above, minus only the loop involving operation six (change 0 to 9). In this case, the instructor need only make sure that the student knows how to test whether the top number in a column is zero, how to change zero to nine, and how to proceed to the next column (operation five) at the appropriate points. Where a student knows less, one would start with simpler prototypes (partial rules representing what the student knows) and gradually elaborate, or add increasing detail until the student has mastered the entire rule.

The above illustration of prescriptive aspects of contemporary instructional theories constitutes only a simple prototype. It “epitomizes” the prescriptive aspects of such theory. Existing theory, however, provides a far more generalized basis for instructional prescription (Scandura, 1977, 1980) which in principle may be used with any subject matter that might be of interest—no matter how complex that subject matter and, if improving instructional efficiency rather than theoretical completeness is the goal, no matter how unstructured.

ALGORITHMIC-HEURISTIC THEORY
LEARNING THEORIES
SCHOOL LEARNING

J. M. Scandura