Components of a Psychology of Instruction:
Toward a Science of Design

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It is a well-known historical fact that two major areas of scientific psychology, psychometrics and general experimental psychology, came out of different traditions and have developed in different ways. Psychometrics has become a major technological application of psychology, with primary effort being devoted to practical techniques and less effort to theoretical concerns. In contrast, the experimental psychology of learning and cognition has been almost exclusively a theoretical endeavor, with little effort devoted to application and the design of practical techniques for assisting in the conduct of human affairs. Although practical work has been carried out in educational psychology, industrial psychology, and human engineering, no integrated body of special technique of application has emerged. In recent years, however, there has been increasing interest in and social pressure for the development of professional techniques for the application of what knowledge there is of

This paper is a revised version of a seminar talk presented at Educational Testing Service, Princeton, New Jersey, June 1974. It also served as the basis for a State of the Science Address at the annual meeting of the Eastern Psychological Association, New York, April 1975. Work on this paper was carried out at the Learning Research and Development Center, University of Pittsburgh, and was supported in part by funds from the National Institute of Education (NIE), United States Department of Health, Education, and Welfare. The opinions expressed do not necessarily reflect the position or policy of NIE, and no official endorsement should be inferred.
learning, cognitive processes, and human development. It appears that some linking of theory and practice needs to take place.

It is of interest to note in this regard that John Dewey, in his presidential address before the American Psychological Association in 1899, expressed concern about developing a linking science between psychological theory and practical work. Dewey said the following:

"Do we not lay a special linking science everywhere else between the theory and practical work? We have engineering between physics and the practical workingmen in the mills; we have a scientific medicine between the natural science and the physician." The sentences suggest...that the real essence of the problem is found in...[a] connection between the two extreme terms—between the theorist and the practical worker—through the medium of the linking science. The decisive matter is the extent to which the ideas of the theorist actually project themselves, through the kind offices of the middleman, into the consciousness of the practitioner. It is the participation by the practical man in the theory, through the agency of the linking science, that determines at once the effectiveness of the work done, and the moral freedom and personal development of the one engaged in it. (1900, pp. 110-111)

It is the [teacher's] inability to regard, upon occasion, both himself and the child as just objects working upon each other in specific ways that compels him to resort to purely arbitrary measures, to fall back upon mere routine traditions of school teaching, or to fly to the latest fad of pedagogical theorists—the latest panacea peddled out in school journals or teachers' institutes—just as the old physician relied upon his magic formula. (pp. 112-113)

In this paper, my concern is similar to Dewey's, and I would like to speculate on the nature of a "linking science"—a psychology of instruction—between the scientific knowledge of learning (including human cognition and development) and educational applications.


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In the preface, Thorndike wrote as follows:

Within recent years there have been three lines of advance in psychology which are of notable significance for teaching. The first is the new point of view concerning the general process of learning. We now understand that learning is essentially the formation of connections or bonds between situations and responses, that the satisfyingness of the result is the chief force that forms them, and that habit rules in the realm of thought as truly and as fully as in the realm of action.

The second is the great increase in knowledge of the amount, rate, and conditions of improvement in those organized groups of hierarchies of habits which we call abilities, such as ability to add or ability to read. Practice and improvement are no longer vague generalities, but concern changes which are definable and measurable by standard tests and scales.

The third is the better understanding of the so-called "higher processes" of analysis, abstraction, the formation of general notions, and reasoning. The older view of a mental chemistry whereby sensations were compounded into percepts, percepts were duplicated by images, percepts and images were amalgamated into abstractions and concepts, and these were manipulated by reasoning, has given way to the understanding of the laws of response to elements or aspects of situations.

This book presents the applications of this newer dynamic psychology to the teaching of arithmetic. (pp. v-vi)

In this book, Thorndike applied his theory and findings about learning directly to the teaching process. The theory of stimulus-response bonds that made up complex chains of behavior was applied to the analysis of arithmetic tasks; the task of adding integers, for example, was carefully analyzed in terms of S-R bonds that could be taught and observed by the teacher. Thorndike also applied the results of his experimental work on transfer of training and reward in suggesting practical teaching techniques. He rejected the old notion of training general faculties and accepted the fact that training needed to be carried out in more specific contexts. He injected his notions of reinforcement by indicating that students should work on problems where, as a result of carrying out a successful response, a student could see the utility of his behavior.

There is an important difference between Dewey and Thorndike, in terms of the publications I have cited, with respect
to what it takes to translate science into practice. Dewey pressed
for some kind of intermediate linking science. He conceived of a
special structure that intervened between scientific theory and
practical application. Thorndike, on the other hand, was con-
cerned with the more direct application of what he knew about
learning and psychological method to teaching practice. In addition
to his general theory of learning, he brought to educational
topics a scientific approach which involved careful analysis of the
nature of the task, the design of teaching techniques as a
function of his experimental findings, and measurement of what
the task analysis indicated were the components of the perfor-
manace being learned.

Thorndike's approach set a very special pattern: the combina-
tion in one person of the theoretical scientist and the applied
scientist interested in designing instructional procedures. And
since that time, for major advances in the psychology of instruc-
tion, we have come to look for individuals interested in both
fields, particularly someone trained in the science of psychology
who is motivated to look at problems in education. Such a tactic,
however, has its shortcomings. It is a highly individualistic,
noncumulative kind of venture which does not necessarily lead to
the development of a linking science in which knowledge can be
accumulated into a body of techniques and procedures for prac-
tical application by a professional. In contrast, my concern in this
paper is with the possibilities for the development of a linking
structure which, because of its own cumulative strength as a
body of theory and practice, would be less dependent upon the
sporadic interests and insights of individuals.

In the sense described above, B. F. Skinner continued in the
pattern of E. L. Thorndike, and most of those who became
interested in programmed learning and teaching machines con-
tinued to work in this mode. As the field became popular,
however, it took on a superficial momentum that separated it
from the implicit theory that generated it; no substantial struc-
ture was built up into which new data, parameters of application,
and boundary conditions could be placed.

In the late 1950's and early 1960's, as part of a general
Zeitgeist, the notion of a linking science was being nurtured.
Bruner (1964) contrasted the nature of a theory of instruction
with a theory of learning. He pointed out that a theory of
learning is descriptive, whereas a theory of instruction is pre-
scriptive in the sense that it sets forth rules specifying the most
effective way to achieve knowledge or mastery of skills. A theory
of learning describes, after the fact, the conditions under which
some competence is acquired. A theory of instruction is a norma-
tive theory in that it sets up criteria of performance and then
specifies the conditions required for meeting them. Skinner, too,
had made this point in the course of his interest in the technology of teaching, since the nature of his approach to the study of behavior makes the development of procedures for prescribing conditions for learning almost indistinguishable from a theoretical description of learning. Most approaches to psychological knowledge emphasize both the theoretical and empirical description of learning, they have not been concerned with the problems of prescriptive science. There is, however, at the present time a growing feeling that a strong test of the adequacy of descriptive theory in the behavioral and social sciences can be made through attempts at application based upon the development of prescriptive theory for the design of social policy and social institutions, including education.

**The Activity of Design**

The general characteristics of a prescriptive science of design have been discussed recently by Herbert Simon in his book, *The Sciences of the Artificial* (1969). Simon’s ideas on this matter are worth noting here. He points out that it traditionally has been the task of the sciences and other disciplines in the university to describe how things are and how they work, and it has been the task of professional schools to teach how to design and make things. The intellectual activity of design is involved not only in producing material artifacts as in engineering, but also in prescribing remedies for a sick patient, devising a sales plan for a company, constructing a new social welfare policy for a state, and designing a program of instruction for a school system. Simon writes:

> Design, so construed is the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. Schools of engineering, as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design. (pp. 55-56)

In view of the key role of design in professional activity, it is ironic, Simon argues, that prescriptive design sciences are less prominent in professional school curricula than they might be.

Engineering schools have become schools of physics and mathematics; medical schools have become schools of biological sciences; business schools have become schools of finite mathematics. The use of adjectives like “applied” conceals, but does not change, the fact. (p. 56)

Curriculum topics are selected from disciplines that are thought to be most relevant to professional practice; but design, as
Atkinson tasks paired-associate determination work methods action requirements. the quantitative functionai quantities minimum relationship certain number describes more such parameters is of action. set values in ing design techniques in technical psychology intellectually rigorous effort inn education, as concerned with deciding upon optimal courses of action. In very general terms, the technique is this: Given a set of alternative goals or possibilities for action, certain fixed parameters and constraints of the situation, and a function that describes the relationship between these factors, find a set of values that provides the best means of attaining possible outcomes. A stock application of this paradigm, described by Simon, is to the so-called “diet problem.” Given the goal of losing a certain number of pounds; given parameters and constraints such as food prices and nutritional content; and given the relationship between the cost of a diet, calories per day, and minimum needs for nutritional requirements; find the kinds and quantities of food necessary to maximize utility—for example, no more than 2,000 calories per day with proper nutritional requirements. Once such a problem can be formalized in terms of a quantitative functional relationship, then standard mathematical techniques can be applied to maximize the outcome subject to the given constraints. On the basis of this solution, a course of action can be decided upon.

In an exploratory way, the formal apparatus of optimization methods has been introduced into instructional design. Richard Atkinson and his students (Atkinson & Paulson, 1972; Groen & Atkinson, 1968) have described procedures for optimizing paired-associate list-learning of the kind found in initial reading tasks or in learning the vocabulary of a second language. This work makes it clear, however, that at the present time, the determination of optimal alternatives is a relatively easy matter only in “trivial” cases. Atkinson is careful to point out that
formal uses of optimization routines developing out of linear programming theory, dynamic programming, and control theory are of little help for the complex performances and instructional procedures of most interest in education. However, his work to date on simple cases might help clarify some of the steps involved in devising and testing optimal instructional strategies.

A significant problem in using optimization methods is the requirement for a formal description of the functional relationships involved. If one can employ a formal model like statistical learning theory, then standard optimization methods can be applied. However, such formal descriptions are not readily forthcoming for the complex cognitive tasks and instructional procedures that are of central interest to educators. For progress now, on the basis of our current knowledge and ability to model and describe the learning process, new kinds of prescriptive methods are required. But still, descriptive theory of some kind is a necessary prerequisite for prescriptive theory if the design procedures we will use in the design of instruction are to be at all like the procedures used in other professions. Of significant interest is that instructional design—the development of instructional procedures and methods—can also become a strong way of testing descriptive theory.

**Questions for Instructional Psychology**

For the development of an instructional psychology, there are two questions that need to be asked, the first methodological and the second substantive. The first is: What can be learned about techniques to be used in the application of psychological knowledge to the design of instruction from the strategies of design used in other fields? One answer to this question recognizes the fact that an effective design strategy incorporates procedures for identifying admissible alternatives and then proceeds to make decisions about the most satisfactory of these alternatives. In this regard, a main lesson to be learned from the work to date is that design is not merely assembling a problem solution from what is known, but is rather a search for the most appropriate assembling of the components involved. The components of a design problem need to be assembled into a number of alternative procedures; exploration of these tentative paths then needs to be pursued so that the most promising ones can be followed up and the less promising ones given a lower priority. The design process essentially involves the generation of alternatives and the testing of these alternatives against practical requirements, constraints, and values. This is not done in a single generate-and-test cycle, but through an iterative series involving the generation of alternatives, testing them (through actual small-
scale studies or through simulation), describing revised alternatives, testing them, and so on. This will take us away from the intuitive, one-shot innovation model of educational reform to a mode of operation in which reforms are seen as actual or simulated experiments, with each experiment providing information for successive improvement and refinement of possible alternatives.

A second question to be considered is: Given methodologies for deciding among possible alternatives, what are the substantive components that are required as the data to which these methodologies can be applied? This question is a large one for psychological research, and discussion of it will comprise the remainder of this paper. Regardless of the descriptive theory with which one works, four components of a prescriptive theory for the design of instructional environments appear to be essential: (a) analysis of the competence, the state of knowledge and skill, to be achieved; (b) description of the initial state with which learning begins; (c) conditions that can be implemented to bring about change from the initial state of the learner to the state described as the competence; and (d) assessment procedures for determining the immediate and long-range outcomes of the conditions that are put into effect to implement change from the initial state of competence to further development. These components of a psychology of instruction comprise the information—the parameters, constraints, and functional relationships—that is required for employing procedures to optimize instruction or for deciding between instructional alternatives. I shall discuss each of these in turn, but before doing so, let me give you some feeling for the general nature of the kind of individual cognitive development with which I am concerned here and to which the above components refer.

The Development of Competence

The process of instruction, as distinguished from education in general, is, to a large extent, concerned with the development of the behaviors and cognitive structures that differentiate between the novice and the competent performer in a particular subject matter and intellectual skill. In attaining this knowledge and skill, the learner proceeds through a novitiate stage and then on to a stage of relative expertise; he or she learns to be a good reader, a competent mathematician, a deep thinker, a quick learner, a creative person, an inquiring individual, and so on. Competence in these activities is assessed according to criteria of expertise established by the school and the community; more specifically, it is assessed by subject-matter requirements, peer-group expectations, and the general social and professional
criteria for what constitutes low, average, and high levels of competence. The educational and social community adjusts its expectations to the competence level of the learner so that initially awkward and partially correct performances are acceptable, whereas later, they are not.

The changes that take place as an individual progresses from ignorance to increasing competence are of the following kinds: (a) Variable, awkward, and crude performance changes to performance that is consistent, relatively fast, and precise. Unitary acts change into larger response integrations and overall strategies. (b) The contexts of performance change from simple stimulus patterns with a great deal of clarity to complex patterns in which information must be abstracted from a context of events that are not all relevant. (c) Performance becomes increasingly symbolic, covert, and automatic. The learner responds increasingly to internal representations of an event, to internalized standards, and to internalized strategies for thinking and problem solving. (d) The behavior of the competent individual becomes increasingly self-sustaining in terms of skillful employment of the rules when they are applicable and subtle bending of the rules in appropriate situations. Increasing reliance is placed on one's own ability to generate the events by which one learns and the criteria by which one's performance is judged and valued. It is the understanding and facilitation of this process of change from ignorance to competence, from novice to expert, that is a major focus of the emerging psychology of instruction. Consider now the components required to facilitate this process.

Components of a Psychology of Instruction

The Analysis of Competent Performance

Central to a concern with instructional processes is the problem of task analysis; analytic description is required of what it is that is to be learned. What has a competent performer in a subject-matter domain learned that distinguishes him from a novice? What distinguishes a skilled reader from an unskilled one? When a task analysis identifies the properties of a certain class of performance, then inferences can be formulated and tested concerning optimal instructional processes for acquiring these performance abilities. Analyzing the content of instruction means studying tasks considerably more complex than those typically studied in the laboratory. It also requires techniques for the detailed analysis of performance in terms of the demands placed on cognitive processes and on knowledge and skills assumed to be in the learner's repertoire as acquired through instruction, development, or self-learning.
The requirement for the analysis of competent performance is related to the specification of behavioral objectives so strongly advocated by many educational psychologists. This salutary advice given by behavioral psychologists is now being taken seriously by cognitive theorists concerned with the cognitive components of criterion performance. There seem to be two main aspects to such an analysis. One is the identification of the information structures that are required for performance, and the other is a description of the processes and cognitive strategies—heuristics and algorithms—that need to be applied to this information, and which themselves are part of the information data base.

As an interesting case in point, consider the work that has been going on in the cognitive simulation of expert chess players. An article by Simon and Chase (1973) summarizes differences between novice and average players, and masters and grandmasters in chess. They indicate that the most likely explanation for the extraordinary skill of the chess master is that he is acquainted with tens of thousands of familiar patterns of pieces, and he associates many of these patterns with plausible moves by taking advantage of the informational features represented by the patterns. The basic heuristics that guide the search for good moves are based upon the perceptual ability to recognize an informational pattern on the board. "For example," Simon and Chase point out, "every chess player of even moderate skill is familiar with the advice: 'If there's an open file, put a Rook on it'" (p. 402). The pattern of an open file triggers this heuristic and initiates a move in a heuristic search for the best move. For a chess master, hundreds of immediately recognized patterns may be associated with an algorithmic solution—i.e., moves that lead to the guaranteed win of a piece or a checkmate—so that a series of moves may be played almost by rote. The key to understanding chess skill lies in understanding the large perceptual vocabulary of piece configurations, the associated algorithms, and the particular perceptual processes involved in this skill.

From an instructional point of view, the target behavior of interest is that the chess master's performance seems to involve a buildup in long-term memory of a

vast repertoire of patterns and associated plausible moves. Early in practice, these move sequences are arrived at by slow, conscious heuristic search—"If I take that piece, then he takes this piece ..."—but with practice, the initial condition is seen as a pattern, quickly and unconsciously, and the plausible move comes almost automatically. Such a learning process takes time—
years—to build the thousands of familiar chunks needed for master-level chess. (Simon & Chase, 1973, p. 408)

It is to be noted further that grandmasters may possess exceptional talents along certain dimensions, but their talents are chess-specific. There is no evidence that masters demonstrate more than above-average competence on basic intellectual factors. Thus, the acquisition of chess skill depends, in large part, on building up specific recognition memory for many familiar chess patterns. In a psychology of instruction, this kind of contrastive analysis of the informational content and skills of competent performers and novices might be prototypic of the kind of research that is especially relevant to an understanding of the objectives of instruction.

Consider another example of work on simple arithmetic problems and the nature of competent performance in addition and subtraction. Studies carried out by Suppes and Groen (1967); Woods, Resnick, and Groen (1975); and Resnick (in press) suggest an interesting relationship between what children are taught to do and how they eventually perform efficiently. Young children are generally taught to solve a single-digit addition problem such as \( 6 + 8 \) by an algorithm in which they count out six blocks, then count eight blocks, and then count to combine the set. With practice, children perform this smoothly; when the blocks are taken away, they frequently shift to counting on their fingers, and then eventually shift to internal processing. When the nature of this internal processing is examined, it is found that most children carry out addition by using what has been called a “choice model.” They appear to set a mental counter to the magnitude of whichever number is larger and then increment by the smaller number. Some children retain the earlier model used in instruction—that is, they increment six times, then increment eight more times, and then read their mental counter. The most efficient children, however, appear to be able, without direct instruction, to convert a routine that has been taught into a different routine—a routine that shows they have discovered commutativity and have developed a performance that requires fewer steps. It is to be noted that the initial teaching procedure reflected the rational “union of sets” definition of addition, and thus is a mathematically correct procedure that represents the subject matter clearly and provides a routine that is easy to demonstrate and learn. For an efficient performer, however, the routine is awkward and slow. Thus, the routine derived by rational analysis of the subject-matter structure is transformed to a performance routine that reflects a more sophisticated definition of the subject matter.
What are the implications of this analysis? On the face of it, it would seem that we ought to abandon the algorithm suggested by direct analysis of tasks in favor of analysis of skilled performance. We can argue that the rational analysis of tasks may not match skilled performance and that it therefore should not be used as a basis for instruction. It would seem best to carry out detailed empirical analyses of skilled performance on subject-matter tasks and teach the routines uncovered by such analyses. However, in discussing her work, Resnick (in press) points out that such a conclusion could be in error, since it rests on the assumption that efficient instruction is necessarily direct instruction in skilled performance strategies rather than instruction in routines that put learners in a good position to invent or derive efficient strategies for themselves. So, it is implied that the teaching routines in elementary arithmetic were not poor ones that inhibited the acquisition of efficient performance, but may have been good ones that fostered the invention of more efficient algorithms.

As suggested by the above examples, the work on the analysis of competent performance that is going on at the present time is of two kinds: the characterization of the information structures and cognitive processes of the skilled performer, and behaviorally oriented work on rational task analysis. Such analyses of human competence and subject-matter tasks may allow us to do two things regarding the optimization of instruction: (a) Specifying the structures and processes by which competent individuals might be performing a task may put us in a position to try to teach these processes to individual learners. (b) Knowing that a task is performed efficiently in one way rather than in another might enable us to design instruction so that the performance learned allows individuals to directly or indirectly transfer to the more efficient method.

It would be a serious omission to leave the topic of task analysis without referring to the influential work of Robert Gagné on learning hierarchies (1962, 1970). This theory continues to be widely accepted as a framework for investigating instructional processes and for designing educational procedures and curricula in various subject matters. Gagné has presented us with a system for rational task analysis based upon a cumulative learning model that states that there are different types of learning, with the simpler types being prerequisite states for learning the more complex types. For example, problem solving, a complex higher-order type of learning, requires rule learning, a lower-order task, as a prerequisite; and rule learning, since rules consist of relationships between concepts, requires concept learning as a prerequisite; and so forth. In general, the lower-order task is defined as being prerequisite to a higher-order task...
when competence in the simpler task facilitates positive transfer in learning the more complex task.

In addition to a clear-cut transfer relationship, there are, however, several possible relationships that might exist between prerequisite tasks and superordinate tasks. The lower-order task might be one of a number of components of the more complex task, each of which can be acquired independently of the others, but all of which must be combined to produce the higher-order performance. Alternatively, the lower-order tasks may themselves be hierarchically related to one another, constituting a sequenced progression leading to increasingly complex performance. Lower-order tasks may also be competencies which facilitate the learning of the more complex task, but which drop out in the more “skillful” performance. Furthermore, the lower-order tasks might function as heuristics for discovering or inventing procedures for carrying out the more complex task. Research along these lines, i.e., investigating the acquisition of complex performance on the basis of existing competencies, is especially relevant for instructional psychology.

Description of Initial State

Instruction begins with an initial state of the learner, and instruction proceeds on this base toward the development of competent performance. There are two approaches to this component of instructional design: “immediate” and “long-term.” The immediate approach is to take seriously the fact that effective instruction requires careful assessment of the strengths, weaknesses, styles, and background interests and talents of individual learners. What are the details of what a child knows and does not know at particular points in his or her learning? What are the details of the skills that he or she is developing? What needs to be improved? What strengths can be capitalized on? What do various developmental levels and various cultural backgrounds mean for what should be taught and how it should be taught? Educational practices need to be designed so that answers to these kinds of questions are possible for all individuals attending school. Teachers and students need to be in a position to obtain and utilize this kind of information; with it, teachers can prescribe the instruction required, and students can assess their own abilities and select appropriate instruction.

The use of procedures for providing this kind of information for teaching requires the adoption of an attitude that looks upon the information obtained as information for improving instruction, and not simply as a test for evaluating and classifying students. For this purpose, it has been useful to provide teachers with hierarchies of increasing competence in various school subjects
(Resnick, Wang, & Kaplan, 1973). These take the form of "structured maps" into which a teacher can place a child and thereby direct attention to prerequisite skills that might need to be learned or advanced skills that the child might explore. The hierarchical map serves as a guide upon which both the teacher and the child can impose additional judgments. The provision of procedures for identifying the current competence and talents of the learner in a way that provides a basis for instruction is generally not done in current educational methods at a level of detail necessary for the effective guidance of individual learners. The implementation of such procedures is not only a matter of research, but also largely a matter of administrative change and the design of appropriate materials.

The more long-term approach derives from the fact that aptitude and intelligence tests are the prevalent methods for assessing initial states that are, to some extent, predictive of eventual educational success, but these measures do not provide sufficient information about instructional processes (Glaser, 1972). Having been devised primarily for purposes of selection, these measures do not provide a basis for deciding how instruction might be designed to make the attainment of successful performance more probable. The significant requirement in this regard for a psychology of instruction is to describe the initial state of the learner in terms of processes involved in achieving competent performance. This would then allow us to influence learning in two ways: (a) to design instructional alternatives that adapt to these processes, and (b) to attempt to improve an individual’s competence in these processes so that he is more likely to profit from the instructional procedures available. There is, at the present time, a spurt of interesting research devoted to analyzing the underlying cognitive processes that contribute to intelligence and aptitude-like performance. Three illustrative examples will be presented.

In a recent series of studies by Hunt, Frost, and Lunneborg (1973), students were classified into high- and low-verbal ability groups and into high- and low-quantitative ability groups on the basis of a battery of tests used for selection for college entrance at the University of Washington. The individuals in each of these groups were then given a series of tasks employed in laboratory experiments on the experimental analysis of information processing models of memory. In this way, the characteristics of high-verbal ability and high-quantitative ability students, as defined by aptitude tests, were examined in terms of cognitive processes, as defined by tasks used to investigate particular theories of cognition. The conclusions from the studies tentatively indicate that there is a relationship between verbal ability and the rapidity and efficiency of data manipulation in short-
term memory, and between quantitative ability and resistance to
distraction while consolidating information in short-term mem-
ory.

It is thus suggested that verbal and mathematical aptitude is
related to the nature of information processing in memory, and
the interesting question for an instructional psychology is
whether we can proceed further and identify situations where
the speed and other properties of such processing will be predic-
tive of school achievement. Such an endeavor could have more
significant implications than present correlationally derived re-
lations between aptitude tests and school success because clues
would perhaps be available about how verbal and mathematical
ability processes might be modified or employed for learning.

In a very recent paper, Estes (1974) discusses the digit-span
test that appears on the Stanford-Binet. At year ten, the sub-
ject's task is to repeat a sequence of random digits after they
have been read aloud by the examiner. The test correlates
satisfactorily with the usual validation criteria, but the interesting
instructional question is: If an individual scores low on this
test, what instructional procedure should we expect to be useful
in improving this performance, performance that we know is
correlated with academic accomplishment? Estes describes re-
cent research and theory dealing with short-term memory for
sequences of items that indicate that the digit-span task appears
to involve a hierarchical structure of representations in memory.
A quote gives the gist and flavor of this:

On presentation of the digit sequence of 691472, the
individual is conceived to subgroup the sequence into two
chunks, assigning a code to each which he maintains in
memory, and within each chunk relating the items of the
sequence to the ordinal numbers 1, 2, and 3. On a request
to recall the string, the individual brings into memory his
coded representations of the two chunks; each of these in
turn activates recall of the individual digits and their
associated serial positions. While this process goes on,
the individual must hold the partially reconstructed
sequence in an output response buffer by an inhibitory
process until the decoding is complete and then emit the
digits in the proper order. (p. 743)

Estes points out that such an analysis of performance on the
digit-span task may have implications for assessing individual
differences. Young or mentally retarded children might fail the
test because of insufficient familiarity with the sequence of
ordinal numbers or because of inexperience in ordering materials
with the number sequence. An individual may not perform well
because he has not developed an appropriate strategy of grouping (although he might utilize grouping when prompted by the examiner), is unable to accomplish the coding process necessary to take advantage of chunking, or lacks the capacity for selective inhibition in buffer storage necessary to order his output properly. Estes writes:

Clearly, it would be possible with the advantage of added theoretical insight to augment the standard digit span test in such a way as to localize the source of difficulty for an individual who fails under the standard procedure. This augmentation would quite likely do little to improve the predictive value of the test, but it might be of considerable help in indicating how deficient performance in this and related tasks might be remedied. (p. 744)

Holzman (1975) has studied letter series completion problems of the sort used by the Thurstones (1941) in their factor analytic studies of intelligence. Letter series consist of a sequence of alphabetic characters running in a consistent pattern. In any one test item, usually about a dozen of these patterned letters are presented to the examinee followed by four blank space. The individual must fill in the four blanks with letters that are consistent with the pattern exhibited by the previously presented letters of that series. For example, the individual might see the problem “defgefghgghi - - -” and be asked to fill in the blanks. Work on analyzing this task has been carried out by Simon and Kotovsky (Simon & Kotovsky, 1963; Kotovsky & Simon, 1973), who have obtained protocols of adolescents and adults solving these sorts of problems; then, based on these observations, they wrote computer programs to simulate humans’ solution routines. Four basic component routines are necessary for the simulation of correct solution. The first routine is the detection of relations between letters: Are letters identical, sequential, or sequential in reverse order? The second routine or subskill is the discovery of periodicity in a series. This involves noticing that letter relations repeat themselves at regular, predictable intervals. A third routine, called pattern description, assembles knowledge of letter relations and knowledge of periodicity into a rule that generates the series. The final routine required is extrapolation. This involves remembering the pattern description and using this rule to generate the appropriate letters for the blanks.

Using this information about the possible cognitive processes involved, Holzman taught elementary school children to be very proficient in the detection of relations and the discovery of periodicity. As a result of their training, children were able to
show substantial pretest to posttest gains on a typical letter series completion test. Most strikingly, the children were significantly more able than control subjects to demonstrate perfect posttest solutions to the types of problems which they found difficult on the pretest. Both the control subjects, as a result of repeated testing, and experimental subjects were able to make gains on easy problems, but the children trained on component subskills seem to have acquired an information management strategy that allowed them frequently to reach perfect solution even on difficult problems. The skills taught to the children in this study were quite specific; however, the question is raised about the possibilities for the analysis of abilities that are more general than these and that might provide a basis for truly generative intellectual abilities.

Studies like those I have just described raise the possibility that measures of intelligence and aptitude, analyzed in terms of cognitive processes, will, as Hunt and his colleagues (1973) write, “move many psychometric predictions from static statements about the probability of success to dynamic statements about what can be done to increase the likelihood of success” (p. 118). And furthermore, “Hopefully [this] new viewpoint ... will lead to measuring instruments which are diagnostic, in the sense that they tell us how the institution should adjust to the person, instead of simply telling us which people already are adjusted to the institution” (p. 120).

Conditions That Foster the Acquisition of Competence

This third component of instructional design—the conditions that can be implemented to foster the acquisition of competence—essentially involves the procedures that assist learning and the techniques and materials that are designed into the environment in which learning occurs. In this regard, we should recognize that the little we do know about learning is known in terms of descriptive science. Little investigation has taken place from the point of view of utilizing this information for designing the conditions of instruction. Exceptions to this are the work on behavior modification, the work of Gagné, and the limited work referred to earlier on optimization models for paired-associate forms of learning. However, for the most part, these enterprises have not considered complex cognitive performance in any intensive way. What is required is that research on instruction be cast into the mold of a design science that attempts to maximize the outcomes of learning for different individuals. A new form of experimentation would be called for where the tactic is not to develop models of learning and performance, but to test existing models by using them for maximizing learn-
ing under various conditions. For this purpose, we need a theory of the acquisition of competent performance. Such a theory would be concerned with how an individual acquires increasingly complex performances by assembling the present components of his repertoire, by manipulating the conditions and events around him, and by employing his knowledge of how he learns. With the development of such a theory in mind, some very brief preliminary observations can be made on knowledge structures in memory, on generalized abilities for learning to learn, and on the nature of reinforcement.

Knowledge structures. Some recent work on the semantic structure of information in memory (e.g., Greeno, in press) has been concerned with the semantic networks and information processing mechanisms that are available at different levels of subject-matter competence. If, at various levels of learning or stages of competence, the kinds of knowledge we wish to create in the minds of students can be specified in this way, then some interesting implications are suggested for the relationship among subject-matter structure, curriculum content, and instructional design. One such relationship can be seen by distinguishing between the structure of a subject-matter domain as it is organized by scholars studying that domain and the structure that is devised for teaching it (Glaser, 1973). The structure of a subject-matter discipline, as employed for the purpose of advanced scholarship, consists of theories, concepts, and definitions that serve to make the domain manipulable for the work of subject-matter experts. However, the structures employed for this purpose are not necessarily the most useful for facilitating the learning of an individual at a less advanced level of development or subject-matter sophistication. Good theory for the scholar may not be good pedagogical theory; what leads to knowledge for the expert may neither lead to knowledge for the novice nor help him to develop competence. It follows that a significant consideration for instructional design is the organization of curriculum sequences that provide knowledge structures optimally organized for moving the novice toward expertise. Appropriately designed structures for learning can reduce the amount of information that must be held in mind to comprehend the subject matter; for example, a verbal label, a conceptual formulation, or a rule or principle may help to organize and summarize a large number of observations. The rule can be thought of as a structure or representation by which an individual is directed or directs himself to look at the relevant features of what might otherwise be an unorganized task situation. As a consequence, a student can generalize across the superficial details of the limited set of experiences encountered in instruction (Gilbert, 1962). Some ways of organizing information may permit better
memory retrieval than other ways and, as a result, facilitate the learner’s capacity to learn new things on the basis of what he has already learned and to access information readily for thinking and problem solving. The organization of subject-matter content can do for the learner what advanced theory does for the expert. Such organizations, however, are not readily available; they are sometimes devised by ingenious teachers and built by them into instructional procedures. I would further suggest that the nature and the design of these organizations or pedagogical structures are a unique province of study for a psychology of instruction.

Teaching generalized learning-to-learn abilities. In the acquisition of competence, a significant instructional consideration is the way in which individuals use their current competence and components of their repertoire for learning new higher-order performance or for solving problems that lead to learning this higher-order performance. Thus, an appropriate concern for instruction is the possibility for teaching general strategies that will help individuals learn on their own and be less dependent on the instructor’s elegance in presenting particular tasks. An interest in teaching such general “learning to learn” abilities has been widely expressed by educators and psychologists, but at the present time, there is little scientific basis for such instruction. One possible basis can come from the studies already described on the process analyses of aptitude-like skills. Still another potential basis for such instruction might be provided by the growing number of information processing analyses of problem-solving tasks.

In a recent paper, Resnick and Glaser (in press) argue that the processes involved in certain kinds of problem solving are probably similar to the processes involved in learning in the absence of direct or complete instruction, and that instruction in these processes might constitute a means of increasing an individual’s generalized learning-to-learn abilities. A model of problem solving was developed in which three interacting phases were identified: (a) problem detection, in which the inapplicability of “usual routines” for solving a problem is noted and a problem or goal is formulated; (b) feature detection, in which the task environment (the external situation, which includes both physical and social features) is scanned for cues that might lead to appropriate actions; and (c) goal analysis, in which goals are successively reformulated, partly on the basis of external task cues, in order to yield soluble subgoals that contribute eventually to solution of the problem as presented. A study by Schadler and Pellegrino (Note 1) has shown that requiring subjects to verbalize their goals and strategies in each of these phases, before making overt moves toward solution, greatly enhances the
likelihood of problem solution. Along these lines, it seems reasonable to anticipate that ways can be found to make individuals more conscious of the role of environmental cues in problem solving. Individuals might be taught strategies of feature scanning and analysis that will enhance the likelihood of their noticing cues that prompt effective actions while somehow "deactivating" those cues that prompt ineffective actions. Such self-regulation could be a major characteristic of successful self-learning and problem solving. The specific suggestions that can be offered at this time for instruction of such generalized learning abilities are limited, since relatively little has been done on developing task analyses that characterize these general processes in instrucutable terms; but work on problem solving is especially relevant to this important goal of instruction. Related to this is work on reinforcement effects to which I now turn.

Reinforcement. Contingencies of reinforcement pervade the acquisition of competence. However, with the strong emergence of cognitive psychology, and with awareness of the fact that the bulk of our knowledge about reinforcement is derived from animal studies in simple task situations and from human experimental contexts in which conditions constrain subjects to employ limited behavioral processes, we are in some danger of ignoring the potential influence of reinforcement on complex performance. There is, on the one hand, a strong suggestion of discontinuity in the operation of reinforcement when moving from simple to higher-order behaviors. On the other hand, the view that seems best supported at the moment is that the mechanisms of reinforcement are similar at all levels of development, but variations in response organization result in different phenotypic manifestations (Estes, 1971). As individuals mature, human behavior is organized into higher-order routines and strategies, and it is these large cognitive organizations whose probabilities of occurrence are modified by reinforcing contingencies. It is the nature of the unit of response that may distinguish the mature human learner, whereas the operation of the principles of reinforcement may be similar for different species and different levels of development and competence.

From the point of view of a theory of instructional psychology, we should be further aware that in the natural settings of classrooms reinforcement occurs extensively within a social context. This highlights certain dimensions of the nature of reinforcement that need to be considered in instructional situations (e.g., Bandura, 1971). One aspect is that people continually observe the behaviors of others as this behavior is rewarded, ignored, or punished; and this observation influences the subsequent operation and effect of reinforcers on the observers. This
is the phenomenon of modeling and vicarious reinforcement. A second aspect is that individuals regulate their own actions by mechanisms of self-reinforcement. Self-generated anticipatory consequences allow possible future contingencies to influence present behavior, and self-evaluations of the consequences of one's own actions influence behavior as these consequences are made apparent by classroom reinforcement contingencies.

Assessment of the Effects of Instructional Implementation

The fourth component of instructional design is concerned with the effects of instructional implementation in the short and in the long run—effects that occur immediately in the context of instruction and effects that persist in terms of long-term transfer, generalized patterns of behavior, and ability for further learning. One requirement for this purpose is to break away from the tradition of norm-referenced measurement to measurement more concerned with identifying the nature of competent performance (Glaser, 1963; Glaser & Nitko, 1971). For effective instructional design, tests will have to be criterion referenced in addition to being norm referenced. They will have to assess performance attainments and capabilities that can be matched to available educational options in more detailed ways than can be carried out with currently used testing and assessment procedures. This will be an important part of the development of a psychology of instruction. It is mandatory that testing not stand out as evaluative devices that are an extrinsic and external adjunct of instruction. Tests need to be interpreted in terms of performance criteria so that the learner and the teacher are informed about an individual's progress relative to developing competence. In this way, information is provided for deciding upon appropriate courses of instruction.

The performance measured by tests designed to facilitate instruction needs to be related to processes identified as components of competence. For this purpose, some interesting endeavors can be envisioned. One example is work going on in analyzing the processes involved in the comprehension of written language, stimulated by the work in psycholinguistics and cognitive psychology (e.g., Carroll & Freedle, 1972). This development should be juxtaposed with the fact that there has been a great deal of work on the development of tests of reading comprehension. As we begin to analyze comprehension tasks and relate them to theories of semantic memory, imagery, and so forth, we should be able to develop tests that provide us with diagnostic information about component processes that contribute to performance and that can be influenced through instruc-
tion. This kind of activity should change the nature of assessment procedures and provide us the kind of information required for maximizing instructional outcomes.

Another area of investigation that is beginning to provide significant evaluative information about the conditions under which learning takes place in school contexts should be mentioned. This is the growing sophistication in the study of the nature of classroom processes. In the past, we essentially attempted to describe school learning by relating the nature of student input to the quality of student output; but the process intervening between the two, the independent variable, was only generally described. Detailed information was rarely obtained about differences between effective and less effective classroom processes.

There are now a number of attempts to research these details. I am especially impressed by the model for such research being developed by my colleague, William Cooley, in conjunction with Paul Lohnes (Cooley & Lohnes, in press). Their model is derived from Carroll’s 1962 model of school learning and consists of six components: (a) initial ability, which reflects the basic incoming skills and general intellectual development of children in a classroom; (b) opportunity, which describes the relative proportion of classroom activities (the dominant classroom subject-matter themes) that are directly related to the assessed outcomes of instruction; (c) motivation, which reflects a student’s tendency to engage in learning activities when the opportunity exists, and operationally defined (in elementary school classrooms) as the fit between the learning situation and the child’s needs, and the relative incidence of teacher praise and encouragement and their antitheses for particular pupil behaviors; (d) structure and placement, which reflect the extent to which the curriculum is structured by specifying objectives, sequences of instruction, particular methods used in differentiating students or in individualizing instruction, and, in general, the organization of instruction and teaching materials; (e) instructional events, which reflect the relative incidence of teacher-pupil instructional interaction and observed, for example, through the extent of teacher acknowledgment of, and feedback with respect to, a student’s task-related activity; (f) criterion ability, which reflects end-of-year student performance, for example, on standardized achievement and intellectual ability tests.

After obtaining information on these components of instruction, a multivariate analysis procedure is used to determine the regression of criterion ability on the other five components of the instructional model. This permits an analysis of the total variance represented in the criterion variable that is explainable in terms of the other components—(a) variance due to incoming
ability independent of classroom process variables, (b) variance uniquely due to the classroom process variables independent of initial ability factors, and (c) variance due to the interaction or overlap between initial ability and instructional processes. In this way, detailed information is obtained on the kind of classroom implementation of an instructional system that is effective or ineffective in producing school outcomes. What is of particular interest in research of this kind is that we can begin to relate the effectiveness of school implementation procedures to psychological dimensions of learning theory and to a theory of the acquisition of competence. Each endeavor can reinforce or challenge the findings of the other.

To conclude: A speculative outline of a psychology of instruction as a science of design has been presented. Directions in which it might develop and what some of its substantive components might be have been suggested. There is much to be done, but many promising leads are now offered for testing fundamental theories of human learning and cognition and for contributing strongly to educational practice.

Reference Note


References


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