What Is The Design Science Of Instruction?

Charles M. Reigeluth
C. Victor Bunderson
M. David Merrill

Brigham Young University

Abstract

This paper is an attempt to identify what instructional science is and what instructional scientists do. *First*, prescriptive design sciences are distinguished from descriptive sciences in general, and instructional science is characterized as a prescriptive design science. *Second*, three major phases of instructional development are described (design, production, and validation), and three approaches for each phase are identified (artistic, empirical, and analytic). The design science of instruction is described as being the foundation for one of the three approaches (the analytic) to one of the three phases (design) of instructional development. *Third*, typical activities of people in instructional science are described. Like all design sciences, instructional science has three types of professionals: scientists, technologists, and technicians. The major activities of instructional scientists are the derivation and validation of prescriptive principles of instruction. *Fourth*, a four-stage theory-construction procedure is proposed as a particularly promising methodology for instructional scientists to conduct their activities of deriving and validating prescriptive principles and theories of instruction. *Fifth*, reference is made to recent work by one instructional science laboratory which uses this four-stage theory-construction procedure. And *finally*, the controversy over basic vs. applied research is addressed from the perspective of the previous analyses.

What is The Design Science of Instruction?

The major products of the science of instruction are prescriptive principles of instruction. These principles allow instructional designers to prescribe instructional methods that are likely to be optimal for given sets of conditions, and they help instructional evaluators to identify methods that are not optimal for given sets of conditions. Therefore, the fundamental purpose of the science of instruction is to contribute to improving the quality of instruction.

A Science of Instruction vs. a Science of Learning B. F. Skinner (1954, 1965) pioneered and popularized a scientific approach to the study of instruction with his programmed instruction movement. For the first time, the emphasis was clearly placed on investigating *instructional* variables (i.e., how information is presented to the student) rather than on investigating *learning* variables (i.e., how learning occurs).

Jerome Bruner (1964) also helped establish the foundations of a science of instruction, except his was a more cognitive approach. A tremendous contribution was his distinction between the *prescriptive* nature of theories of instruction and the *descriptive* nature of theories of learning.

From another perspective, Herbert Simon (1969) elaborated a similar distinction by describing the common characteristics of prescriptive "design sciences" in all disciplines (e.g., business, medicine, engineering) and by contrasting them with the characteristics of their descriptive counterparts (e.g., economics, biology, physics—respectively). In this framework, instructional theory is clearly the prescriptive counterpart of learning theory. Robert Glaser (1965, 1976) also emphasized the importance of developing a prescriptive design science of instruction.

An important aspect of this descriptive-prescriptive distinction is that there is only one type of professional in a descriptive science—the scientist—whereas there are three types of professionals related to a prescriptive science—*scientists*, who discover principles[1], *technologists*, who use those principles to develop procedures[2] or machines, and *technicians*, who use those procedures or machines to produce products. More will be said about these three types of professionals below.

The Context of Instructional Science

As was mentioned in the opening paragraph, the fundamental purpose of the design science of instruction is to contribute to improving the quality of instruction. A major aspect of this endeavor is instructional *development*, which can be conceptualized as having three major phases: (1) *design*, which is, for an instructional developer, what a blueprint is for a builder, (2) *production*, which is the using of the design to make an instructional program and (3) *validation*, which is the determination of the quality or validity of the final product.

Three Approaches to Each Phase Although design, production, and validation are essential phases of instructional development, none of these phases necessarily involves instructional science. Merrill (1975) proposed that there are three major approaches—artistic, raw empirical, and analytic—toward these three phases of instructional development, and that any one of the three approaches can be used on any one of the phases (i.e., design, production, or validation). However, only one of these approaches—the analytic approach—involves instructional science. (Note: these approaches are not mutually exclusive, and each is seldom used in pure form.) Figure 1 characterizes the three approaches.

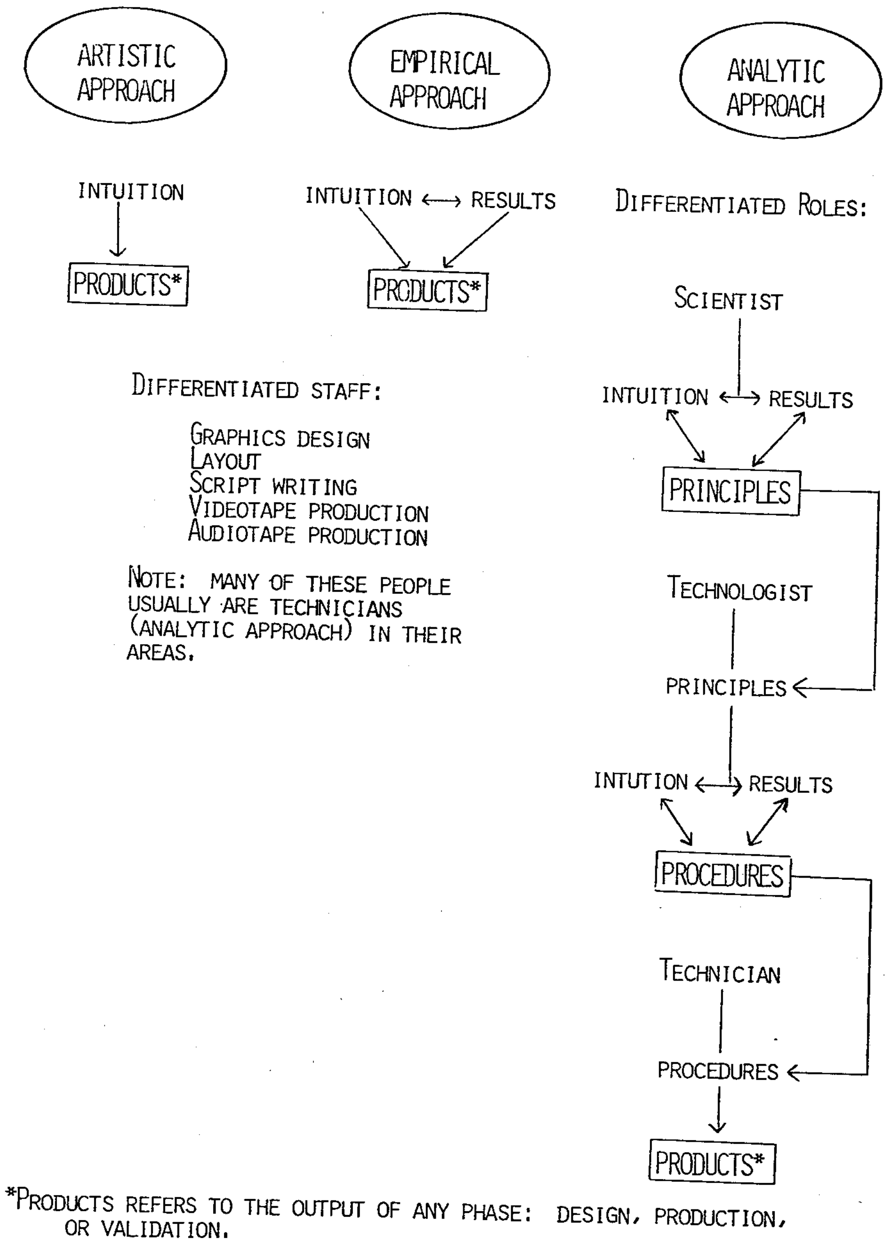

Figure 1. Three approaches to the design, production, or validation of instructional products, and the differentiation of roles within the analytic approach.

The *artistic approach* is subjective and entails the use of intuition, taste, and experience for designing, producing, or validating instructional programs. A person using the artistic approach might say: "I am going to develop the instruction this way because it *feels* right."

The *raw empirical approach* is an extension of the artistic approach. It entails the use of both intuition and results (data) for designing, producing, or validating programs; but the results must be product-specific, and each product must be developed by trial-and-error: try something on the basis of intuition, and collect data to see if it works. A person using the raw empirical approach might say: "I had a feeling that the final product should be like this; but when I tested its quality, I found it was poor. Judging from the problems encountered, I think I'll try these modifications and see if it will then be acceptable."

The *analytic approach* entails the use of prescriptive principles of instructional design, production, or measurement for doing each of the three phases of development: design, production, and validation respectively. The instructional developer follows procedures which are based on principles that have already entailed intuition for their derivation and results (research) for their validation. Therefore, intuition ("art") and results ("empirics") are of minimal importance for conducting any given phase of instructional development; data are usually still needed in the systematic validation of the final product—the third phase—but they are not needed to test the procedures of design, production, or validation. A person using the analytic approach might say: "Since the students have these characteristics and the subject matter content has these characteristics, the following instructional strategies should be used."

An artist or raw empiricist may in fact use some principles in his/her approach to any single phase. However, those principles are usually of "local" derivation; they usually have not been empirically tested; and they are often not made explicit by the artistic or raw empirical developer.

As was mentioned above, any one of the three approaches toward instructional development (i.e., artistic, raw empirical, and analytic) can be used on any one of the three phases (i.e., design, production, or validation). But the artistic, raw empirical, and analytic labels are often used to describe the commonly-used approaches to the *whole process* of instructional development. Nevertheless, a label so used seldom applied accurately to all three phases. For instance, what is commonly referred to as the raw empirical approach to the whole process of instructional development usually entails an analytic approach (rather than a raw empirical approach) to the validation phase—that is, it entails a set of well-tested measurement techniques or procedures which are based on proven principles. Therefore, it is much more helpful to describe the approach used on *each phase* rather than to use one approach descriptor to refer to the whole process of instructional development.

For all three phases (i.e., design, production, and validation), we propose that the analytic approach is preferable to the other two approaches for the following reasons: (1) it saves time and money by reducing the need for revision, because the principles and procedures (of design, production, or validation) have been proven effective for specific conditions; (2) it saves money by allowing less-costly (easily-trained) technicians to do the development work by properly following some validated procedures, and (3) it leads to more consistent high quality of the final products of each phase because it is based on knowledge (principles) accumulated on a much broader scope than personal experience — the most effective methods are more likely to be overlooked by the other two approaches.

Context So where does instructional science fit into this broad picture of phases (i.e., design, production, and validation) and approaches (i.e., artistic, raw empirical, and analytic) of instructional development? Of the three phases, validation relies primarily on methods of measurement, and production relies primarily on methods of organization and media production (including print); only design relies on methods of instruction. And of the three approaches, the artistic requires primarily intuition, and the raw empirical requires primarily data (and intuition); only the analytic must be supported by a scientific base of prescriptive principles. Therefore, instructional science is the foundation of the analytic approach to the design phase of instructional development (see Figure 2).

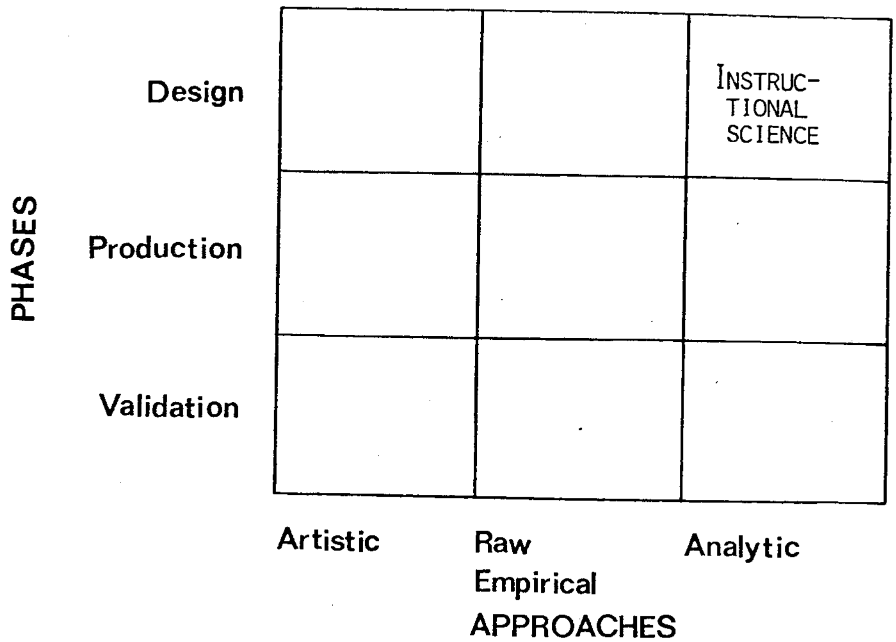

Figure 2. The three approaches to instructional development can be used on any of the three phases of instructional development. Instructional science is the foundation of one approach to one phase.

Some instructional scientists (including Bunderson) interpret the scope of instructional science more broadly to include the analytic approach to the production and validation phases; however others (including Reigeluth and Merrill) view these phases as being supported by completely different types of principles which are derived and validated by other design sciences.

There is one major problem with the foregoing analysis of approaches. Although analytic approaches to production and validation are feasible because of the development of design sciences which support them, an analytic approach to instructional design is not yet broadly feasible because the young design science of instruction has not yet developed the necessary procedures for instructional design nor even derived the prescriptive principles from which those procedures can be developed. Therefore, there is a great need for highly capable people to be attracted and encouraged to help develop this important design science.

What is Instructional Science?

Instructional science, like all prescriptive design sciences, has three types of professionals related to it: (1) *scientists,* who discover principles[1], (2) *technologists,* who use those principles to develop procedures[2], and (3) *technicians,* who use those procedures to produce instructional products. The technician who uses procedures need not be the same person who developed those procedures nor the one who derived and validated the principles upon which those procedures are based. These three roles are referred to as differentiated because each entails a distinct activity (or activities) which require(s) different types of abilities and training.

Figure 1 illustrates the differentiation of roles within the analytic approach by indicating the nature of the activities of each type of professional. The analytic approach is the only one that specifically uses principles and procedures based on those principles; hence it is the approach that permits a useful differentiation of roles. In either the artistic or raw empirical approach there may be novices who imitate the techniques of the artist or the empiricist: such a person is usually called an apprentice. However, he lacks the professional expertise to do the work by himself. Hence, there is a trainer-trainee relationship, but there is no true differentiation of professional roles because the apprentice is not a professional who does a distinct activity that requires different types of abilities and training from those of his trainer. An artist or raw empiricist may often have a differentiated professional *staff,* but that staff is composed of professionals in different areas (e.g., graphics design, layout, videotape production), rather than of professionals at different levels within a single area.

Instructional scientists, like artists and raw empiricists, use intuition; however, intuition is used to produce *principles* rather than products. Intuition is also used by instructional scientists to design research for testing hypothesized principles, and the results are used to subsequently modify the hypothesized principles if necessary. In addition, new principles and results influence intuition (hence the two-way arrows in Figure 1). Thus, an interactive triad forms the core of instructional scientists' activities, with prescriptive principles of instruction as the output.

Instructional technologists apply the scientists' principles to the development of instruction. Again, this entails the use of intuition; however, intuition is used to produce *procedures* for applying the principles in development projects, rather than to produce raw principles. These procedures should also be empirically tested, both for efficiency and cost as well as for the effectiveness of student learning from the resulting product. Thus, another interactive triad forms the core of the instructional technologists' activities, with validated procedures for instructional design as the output.

Finally, *instructional technicians* (the developers for whom instructional scientists and technologists exist) use the technologists' procedures to produce instructional *products*. An instructional design technician must have a good knowledge of the "tools" of his trade—such as writing techniques, instructional design components and terminology, and the procedures of instructional design. His skills are mainly concept-classification and procedure-using. Intuition is no longer the most important requirement; hence competent instructional technicians can be trained relatively quickly and inexpensively. Also, at this level, research (*generalizable* results) effectively drops out, and *specific* evaluations are used to test *specific* instructional products. However, because these instructional products have been designed using empirically validated principles and procedures, the probability of success is considerably enhanced, and the extent of necessary revision is greatly reduced. Although both research and evaluation are concerned with empirically testing instruction, research does so on the principle and procedure levels (hence the concern with external validity), whereas empirical evaluation tests instruction on the product level.

In summary, instructional science is the foundation of the analytic approach to instructional development; and it entails intuition and research work as inputs and the derivation of prescriptive principles and theories (i.e., sets of interrelated principles) of instruction as its outputs. A major portion of instructional scientists' activities involves analyzing the components of instructional tactics and strategies as to their effectiveness, efficiency, and appeal under different conditions (primarily diverse student characteristics and subject-matter characteristics) in order to derive the prescriptive principles and theories of instruction.

Theory Construction Before the analytic approach to instructional development, with its cost-effective use of technicians, can become feasible, instructional technologists must develop procedures that encompass the use of principles and theories; and before technologists can do that, instructional scientists must derive and validate the important prescriptive principles of instruction and construct and test prescriptive theories or models of instruction. A "top-down" deductive theory-construction procedure (Snelbecker, 1974) would appear to have the greatest advantages. This theory-construction procedure entails: (1) what Snow (1973) referred to as "D-Theory" (descriptive theory and taxonomy) construction, which is the identification, description, and classification of instructional *variables*, both on the "cause" side (i.e., the independent variables), and on the "effect" side (i.e., the dependent variables), (2) the formulation of some basic *postulates* (i.e., hypothesized principles) which relate those independent and dependent variables to each other through the specification of certain tactics or strategies under certain conditions, and (3) the use of these postulates to derive testable deductions, predictions, or hypotheses, and to test the validity of each postulate by systematic *experimental testing* of those hypotheses. Through this continuous process of postulate-generation and experimental testing, instructional science can develop and progress.

But the design science of instruction involves more than the description of separate cause-and-effect relationships. These cause-and-effect relationships are prescriptive and valuable, but they are identified and tested in laboratory-type conditions, i.e., conditions that are carefully controlled so as to eliminate confounding variables and isolate pure effects. Although these relationships may have significant effects in a certain direction under such laboratory conditions, it is likely that their significance may be reduced, and the direction of their effects may even be reversed, in real-world instruction due to the interaction effects of all the other (sometimes unnoticed) variables.

For instance, we hypothesize that an S-shaped curve represents the relationship between the quality of instruction and the effectiveness of that instruction (see Figure 3). Experimenters deliberately design the experimental treatments such that the variable(s) under investigation will increase the quality of the instruction from a-to-b rather than from c-to-d, so that the contribution of that variable to the effectiveness of instruction will be on the order of magnitude of w-to-x rather than y-to-z. In multiple regression (statistics) an independent variable has a much higher correlation with the dependent variable if it is taken alone than if it is adjusted for all other independent variables. The same is probably true of instructional variables in instructional science, such that the significance of any component of instruction is likely to be of a much lower order of magnitude in real, planned instructional settings.

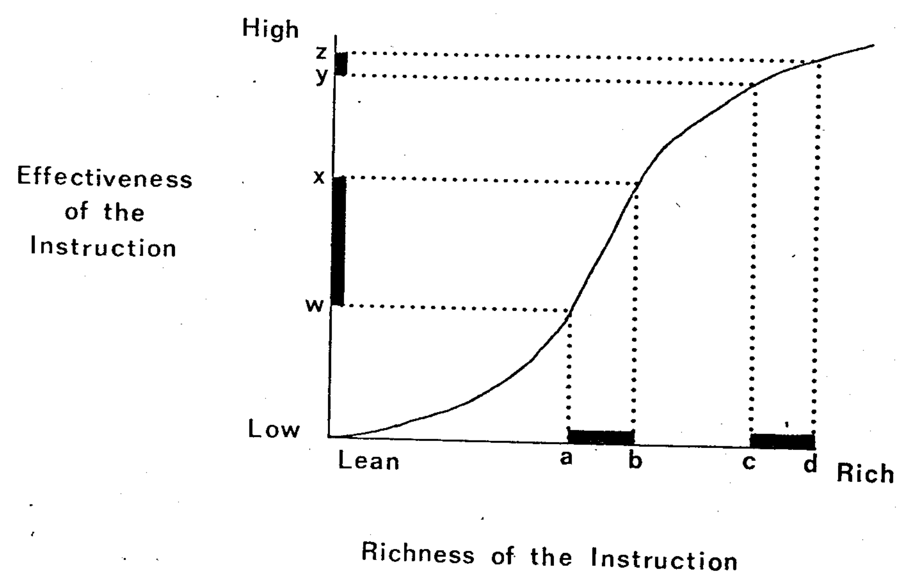

Figure 3. The relationship between the richness of instruction and its effectiveness.

These limitations are serious and require that the theory-construction procedure entail a fourth stage: the testing of instructional strategy variables or components by selectively adding or removing them from *whole systems or models* of instruction. In such a process, it may be discovered that some uninvestigated characteristics, such as some content strategy or instructional management variables, may have a larger impact on instructional outcomes than the most significant of the variables already investigated. Interaction effects can also be more effectively investigated by such a process.

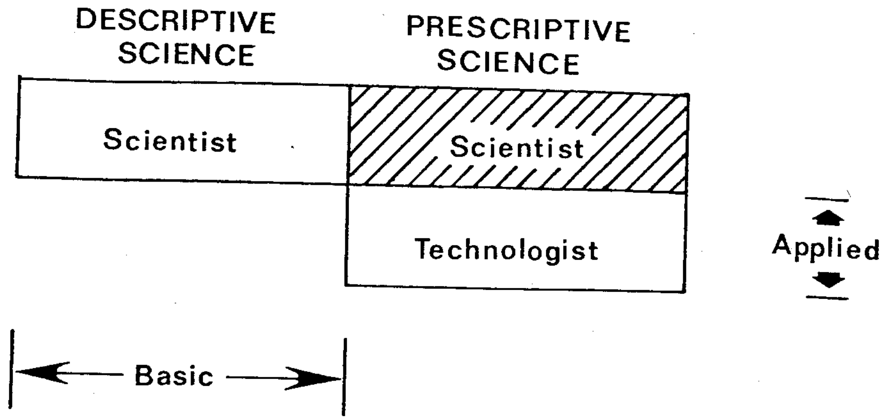

Figure 4. Research at the scientist level in a prescriptive science is classified as basic research by the scientist-technologist distinction but is classified as applied research by the descriptive-prescriptive distinction. Maybe it is a hybrid third type of research that deserves highest priority.

An Example of Theory Construction M. David Merrill and his associates have adopted the above-mentioned theory-construction procedure: (1) the development of a *taxonomy* of instructional variables, (2) the formulation of a few basic *postulates* that relate those variables to each other, (3) the *empirical validation* or repudiation of those postulates through the experimental testing of hypotheses derived from the postulates, and (4) the testing of variables in realistically complex *models or systems* of instruction.

Merrill and his colleagues (Merrill & Boutwell, 1973; Merrill & Wood, 1974, 1975a) have developed a broad taxonomy which identifies, describes, and classifies *presentation strategy variables,* such as attribute isolation, mnemonics, divergent examples, and type of representation. This was a particularly important step, considering that different instructional researchers and theorists often use the same label to refer to different concepts, and different labels to refer to the same concept. A lack of precision in the scientific language of instruction has greatly impeded the communication and interpretation of theoretical and research work.

Merrill and his colleagues (Merrill, Olsen, & Coldeway, 1976; Merrill, Richards, Schmidt, & Wood, 1977; Merrill & Wood, 1975b) have also constructed some basic postulates that relate the instructional variables to each other and to the following three outcomes of instruction: its effectiveness, efficiency, and appeal.

Merrill, Olsen, and Coldeway (1976) conducted a review of research literature to test eight of these postulates. No results were found which were contrary to hypotheses derived from any of the postulates, but "considerable support" was found for only five of the eight postulates, while "partial support" (due to the small number of relevant studies encountered) was found for two, and no relevant research studies were found for one of the postulates.

In summary, while much more work is still needed, the area of presentation strategies has received considerable theoretical development and experimental study. The authors are currently working on the development of a taxonomy of *structural strategy variables,* such as sequencing (ordering) and synthesizing (interrelating) a set of related segments of a subject matter. Reigeluth, Merrill & Bunderson (in press) represents a first step toward that goal.

Applied vs. Basic Research There has been much controversy recently over priorities for applied and basic research (Ebel, 1977; Glaser, 1977; Kerlinger, 1977). Understanding and communication on this issue are impeded by the lack of clear definitions of these terms. However, the foregoing analyses may help to clarify intended meanings for each of these terms.

On the basis of the *descriptive-prescriptive* characterization of sciences, one could define basic research as all the research activities in the descriptive sciences and define applied research as all the research activities in the prescriptive design sciences (both at the scientist and technologist levels). Or, on the basis of the *scientist-technologist* characterization of researchers, one could define basic research as all the research activities performed at the scientist level and define applied research as all the research activities performed at the technologist level. Figure 4 illustrates that the source of ambiguity or misunderstanding on the concepts of basic and applied research lies in the classification of research done at the science level in a prescriptive design science, in this case, instructional science.

Arguments could be made for classifying research in instructional science either way. However, it may be more valuable to classify it as a third, distinct type of research—one that may deserve higher priority than either of the other two types because of its unique combination of basic and applied characteristics.

References

Bruner, J.D. Some theorems on instruction illustrated with reference to mathematics. *Theories of learning and instruction. The Sixty-third yearbook of the National Society for the Study of Education.* Part I, 1964, *63,* 306-335.

Ebel, R. Toward more productive educational research. In W.J. Popham (chair) *Needs and priorities of research and education.* Symposium presented at the meeting of the American Educational Research Association, New York, 1977.

Glaser, R. Toward a behavioral science base for instructional design. In R. Glazer (Ed.) *Teaching machines and programmed learning, II.* Washington, D.C.: National Education Association, 1965.

Glaser, R. Components of a psychology of instruction: toward a science of design. *Review of Educational Research*, 1976, *46*, 1-24.

Glaser, R. Needs and priorities for research in education. In W. J. Popham (chair) *Needs and priorities of research and education.* Symposium presented at the meeting of the American Educational Research Association, New York, 1977.

Kerlinger, F.N. The influence of research on education practice. In W. J. Popham (chair) *Needs and priorities of research and education.* Symposium presented at the meeting of the American Educational Research Association, New York, 1977. Also in *Educational Researcher*, September, 1977, pp. 5-12.

Merrill, M.D. Comprehensive statement of a systematic analytical approach. (Review of *Diagnosis and revision in the development of instructional materials* by G. L. Groper.) *A.V. Communication Review*, 1975, *23*, 446-449.

Merrill, M. D., & Boutwell, R. C. Instructional development methodology and research. In F. N. Kerlinger (Ed.), *Review of research in education*. Itasca, IL: Peacock Publishers, 1973.

Merrill, M. D., Olsen, J., & Coldeway, N. A. *Research support for the instructional strategy diagnostic profile.* Technical Report Series, No. 3. Orem, Utah: Courseware, Inc., 1976.

Merrill, M.D., Richards, R.E., Schmidt, R.V., & Wood, N.D. *The instructional strategy diagnostic profile training manual.* San Diego: Courseware, Inc., 1977.

Merrill, M.D. & Wood, N.D. *Instructional strategies: a preliminary taxonomy.* Columbus, Ohio: Ohio State University, 1974. (ERIC Document Reproduction Service No. SE018-771.)

Merrill, M.D. & Wood, N. *Instructional strategies: a preliminary taxonomy.* Technical Report Series, No. 1R. Orem Utah: Courseware, Inc., 1975a. (a)

Merrill, M.D., & Wood, N.D. *Rules for effective instructional strategies.* Instructional Design Series. Orem, Utah: Courseware, Inc., 1975b. (b)

Reigeluth, C.M., Merrill, M.D., & Bunderson, C.V. The structure of subject-matter content and its instructional design implications. *Instructional Science*, in press.

Simon, H.D. *The sciences of the artificial.* Cambridge, Mass.: MIT Press, 1969.

Skinner, B.F. The science of learning and the art of teaching. *Harvard Educational Review*, 1954, *24*, 86-97. Also in A. Lumsdaine & R. Glaser (Eds.), *Teaching Machines and Programmed Learning*. Washington, D.C.: National Education Association, 1960.

Skinner, B.F. Reflections on a decade of teaching machines. In R. Glaser (Ed.), *Teaching Machines and Programmed Learning, II.* Washington, D.C.: National Education Association, 1965.

Snelbecker, G.E. *Learning theory, instructional theory, and psychoeducational design.* New York: McGraw-Hill 1974.

Snow, R.E. Theory construction for research on teaching. In R.M.W. Travers (Ed.), *Second handbook of research on teaching.* Chicago: Rand McNally & Company, 1973.

Footnotes

[1] As an example of a principle of instruction: "The use of examples which are divergent on variable attributes reduces undergeneralization errors on a concept-classification task."

[2] As an example of a procedure for instructional design: "If the subject matter content is a *concept* and the desired level of behavior for the student is *using the definition to classify instances and non-instances*, then examples which are divergent on variable attributes should be included in the instruction."