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ABSTRACT

The need for an empirically defensible means of sequencing instruction appears to have been the primary motivator for research into learning hierarchies. Four methods for generating candidates for learning hierarchies were reviewed: introspection, formal analysis, observation, and statistical "fishing." Experimental transfer of training studies and statistical studies have been used to evaluate posited hierarchies, and significant modifications of these standard evaluative methods have been suggested to improve the internal validity of research into learning hierarchies. (Author)

SEQUENCING LEARNING EVENTS IN PERFORMANCE-BASED INSTRUCTIONAL SYSTEMS

BY

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SEQUENCING LEARNING

EVENTS IN PERFORMANCE-BASED

INSTRUCTIONAL SYSTEMS

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Belief in the orderliness of Nature has been a kernel idea in Western intellectual history from Greek times to the present. This deeply-rooted belief has acted as an organizing concept in American tradition in the physical and natural sciences as well as in economics. Education has also been influenced by this thinking. If Nature operates in an orderly manner, then it is thought that the most effective methods of conducting the teaching/learning enterprise can be uncovered using the scientist's tools. The study of education as a science is founded on this belief which naturally led to the search for a rational method for organizing schooling. The zeal which characterized this search is evident in Philbrick's (1885) hyperbole: "If America devised the best school desk, it must go to the ends of the civilized world [p.58]."

At the beginning of the twentieth century, reform-conscious America discovered "scientific management" with the help of Frederick W. Taylor (1911). "Scientific management" principles injected the concept of efficiency into American business practices by developing methods for maximizing industrial outputs for a minimum of inputs and, thereby, minimizing the cost of the enterprise and maximizing the return on capital invested. Callahan (1962, esp., p.23 but also passim) documented the spread of applications of "scientific management" dogma to household tasks, family duties, church functions, and, ultimately, the process of education. Not only were the most effective instructional methods pursued, but the comparative costs of substitutable methods were also weighed. The study of the economics of education is rooted in these principles.

Armed with tools such as systems theory, experimental method, educational tests, and cost/effectiveness analysis, instructional systems technicians entered the educational research arena in the liturgical spirit of the educational efficiency movement. And the use of instructional systems has continued to be of cyclical interest to American educators throughout the twentieth century. Interested readers should consult Hambleton (1974) for an analysis of some recent large-scale efforts in this area.

Frantz (1974) and others (Impelliteri & Finch, 1971; University of Wisconsin, 1971) documented the recent upsurge of interest in performance-based, individualized instructional systems in occupational education. However, perhaps it is safe to say that there still exists a lack of coherent and useful theory to guide developers of performance-based instructional systems in occupational education. Recently, though, Lawson (1974a, 1974b) engineered a theoretical instructional design framework in an attempt to resolve this problem. The selection of a sequence for presenting learning events was one component in Lawson's (1974a, p. 55) methodology for the design of performance-based instructional systems.

Gagné (1970, Ch. 4) assigned the term "learning hierarchy" to designate the set of dependencies among component skills within a learning task and suggested that learning hierarchies might define optimal sequences for presenting learning events (see also, Gagné, 1968; Gagné & Bassler, 1963; Gagné, Mayor, Garstens, & Paradise, 1962; Gagné & Paradise, 1961; Gagné & Staff, 1965). Gagné's studies seem to have crystallized the methodological directions for subsequent efforts in learning hierarchy research by instructional systems specialists (White, 1973, p. 367). In performance-based instructional systems, precisely-stated educational objectives define the component skills of learning tasks; the crucial question is whether student's mastery of one objective depends upon their mastery of other objectives.

The purpose of this paper is to supplement and explicate Lawson's instructional-theoretic framework by synthesizing methods available for generating and evaluating learning hierarchies for performance-based instructional systems. A comprehensive list of references to the general problem of sequencing learning events may be found in Marchant and Passmore (1974); this paper contains a review of the methodological papers in this list which are based on the last 10 or 12 years of research on Gagné's conception of learning hierarchies. The usefulness of this paper rests on the assumption that it may be more appropriate to sequence instruction by attending to functional dependencies among objectives in a learning hierarchy than it is to use logical, intuitive sequencing viewpoints (Cf., however, Briggs, 1967, for other sequencing viewpoints).

Generation of Candidates for Learning Hierarchies

A provisional ordering of instructional objectives must be posited before learning hierarchy research can proceed for a particular instructional system. How may these candidates for learning hierarchies be generated? Each researcher uses some method to complete this task even though the range of available methods has not been well documented. And it could be disastrous to operate without a hunch about the starting point for this task. Consider that there are $k!$ possible *linear* orderings for k objectives and that the number of conceivable hierarchies capable of being generated from k objectives is much larger. The sources of hunches about plausible hierarchies may be grouped into four categories: (1) introspection; (2) formal analysis; (3) observation; and (4) statistical "fishing".

Introspection. One popular method for generating candidates for learning hierarchies is to ask the question, "What would an individual need to know or do to display competence in this subject matter?" This same question, paraphrased from Gagné and Paradise (1961, p.4), is applied again to the original answer and, then, successively to subsequent answers. This method of questioning produces a learning hierarchy characterized by general, molar behaviors at the top of the hierarchy and more specific, subordinate, and molecular behaviors near the bottom of the hierarchy (e.g., Gagné, Mayor, Garstens, & Paradise, 1962, p.4).

This introspective method of hierarchy generation most frequently appears in the literature with the instructional system developer the most prominent actor in this process. Variations on this theme include the use of subject matter experts (Payton, 1971) and students (Kaplan, 1964) to play introspective roles to generate learning hierarchies.

Formal analysis. Formal analyses of subject matter domains could provide another source of learning hierarchies. Good examples of such formal analyses are the industrial manufacturing and construction domains developed by the Industrial Arts Curriculum Project (Towers, Lux, & Ray, 1966). Each of these subject matter domains was organized as a hierarchical taxonomy. Levels of each hierarchy proceed from general to more specific elements of manufacturing and construction practice. Within each level, elements were devised to be individually inclusive and mutually exclusive.

Hierarchies supplied by the introspective method previously discussed are developed by imagining the learner's interaction with the subject matter. In contrast, the method of formal analysis removes consideration of the learner and, instead, applies the logical rigor of taxonomic inquiry that has been developed for the natural sciences (see Gregg, 1954).

Observation. Learning hierarchies could also be posited by observing the natural order in which learners acquire behaviors. For example, a problem could be assigned to learners and, then, the milestones in their progress toward problem solution could be recorded. Perhaps observational methods similar to those described by Piaget and Inhelder (1969) for researching hierarchies among development tasks might be fruitful in learning hierarchy research.

While the method of observation introduces a realistic glimpse at learners as a source of learning hierarchies, it must be remembered that the sequence which learners choose to solve a problem may prove to be neither effective nor efficient. And maximum effectiveness and ef ıency in facilitating learning are primary quality criteria for instructional systems.

Statistical "fishing." Also, candidates for learning hierarchies are often captured through statistical studies which may be best characterized as fis..ing expeditions. The prior absence of a hypothesized network of educational objectives is a distinguishing feature of these types of studies. The main aim of these statistical studies is to suggest empirically-based, post hoc, structural hypotheses about the relationships among a set of behaviors.

Many of the numerical techniques, such as hierarchical cluster analysis (e.g., Tryon, 1958) and hierarchical factor analysis (e.g., Coombs & Satter, 1949), applied to military task analysis could be used to fish for provisional candidates for learning hierarchies. A conference report by Moss and Smith (1970, esp. papers by Ammerman, Christal, and Silverman) described the application of military task analysis techniques to the construction of vocational education curricula.

Baker (1972), Chenzoff (1964), Folley (1964), Morsh, Madden, and Christal (1961) reviewed some of the more standard numerical approaches to the development of hierarchical taxonomies of behavior. In addition, a rich and suggestive source of numerical taxonomy methods that could be applied in learning hierarchy research may be found in the natural science literature (For starters see, Sokal & Sneath, 1963 or Sneath & Sokal, 1962). Driver's (1963) survey of numerical clasification methods in anthropology might also be useful.

Another prominent line of thought in learning hierarchy research is that functional dependencies among instructional objectives can be discovered by examining the Guttman (1944) scalability of the test items measuring the behaviors specified by the objectives. Since the success of Guttman's procedure demands a linear ordering of items which measure a unidimensional entity, some researchers have preferred to use Lingoes' (1963) multidimensional extension of Guttman's procedure to uncover non-linear orderings among educational objectives. Airasian and Bart (1971) and Bart and Kruz (1973) developed a similar but more parsimonious technique for discovering hierarchies among test items. Applications of the Bart et al. ordering-theoretic method were presented in Airasian and Bart (1974), Bart (1972a, 1972b) and Bart and Airasian (1972).

Evaluating Posited Hierarchies

An ordering of objectives posited for an instructional system must be evaluated to determine whether it should be rejected, modified, or adopted. Experimental transfer of training studies as well as statistical studies have been used in this evaluation task. Both types of studies were extensively reviewed and heavily criticized by White (1973, 1974a, 1974b) who, as a result, presented (White, 1974c; White & Clark, 1973) significant modifications of earlier paradigms for research into learning hierarchies.

Standard evaluation methods. A transfer of training effect is the action that learning one task has upon subsequent learning or performance of another task (Andreas, 1972, p. 439). Networks of positive -- that is, beneficial and facilitating -- transfer among a set of instructional objectives are frequently sought in the evaluation of learning hierarchies for instructional system design. The definition of a hierarchical relationship as positive transfer among learning events was used in Gagné's pioneering studies which set the tone for most of the learning hierarchy research efforts that followed.

How might mastery of one instructional objective facilitate the mastery of another objective? Several hypotheses are reasonable. First, some identical behaviors may be required to master both objectives. Work habits or specific subject matter skills are examples of identical behaviors that might precipitate transfer effects. Second, positive transfer may occur when similar stimuli and responses are involved in the mastery of both objectives. The psychological mechanisms operating to induce transfer in this case would be stimulus and response generalization.

Transfer of training studies are usually conducted in controlled settings. In the application of such studies to learning hierarchy research, factors, such as warm-up effects and transfer of general work habits must be partitioned from the transfer of specific subject matter skills to unequivocally answer the question, "What is learned?". Murdock's (1957) evaluative review of numerous designs used in transfer experiments might be helpful to learning hierarchy researchers as may the review and critique of methods for measuring transfer effects provided by Gagné, Foster, and Crowley (1948).

In addition to experimental studies, the same methods described as methods for statistical "fishing" for learning hierarchy candidates are also applied in the evaluation of posited hierarchies. Rather than using these statistical techniques to hypothesize hierarchies, the focus, instead, is on testing hypothesized hierarchies.

An interest in validating learning hierarchies not only implies that information will be obtained to discern the appropriateness of the posited hierarchies, but also that the hierarchies will be improved if necessary. However, the range of decisions and decision-making strategies for improving learning hierarchies have not been carefully delineated. For example, one decision that could be made on the basis of experimental or statistical evaluative evidence is that the objectives need to be reordered. Another decision that could be made based on the same data might be that the objectives need to be subdivided, refined, and, then, reordered. An explicit method for rationally choosing between these competing decisions is lacking but could be a fruitful line of future research.

White's modifications. White (1973, p. 371; 1974a, p.1) felt that most evaluations of learning hierarchies were hindered by the following six problems:

(1) small sample size;

(2) imprecise specification of hierarchy elements;

(3) the use of only one question per element to test the dependencies among elements;

(4) the absence of a test of hierarchical independence that takes error of measurement into account;

(5) the practice of testing for dependencies among hierarchy elements after instruction is completed on all elements, thus confounding forgetting with a lack of connection between elements;

and (6) lack of face validity for hierarchies which have been empirically evaluated and improved.

White's solution to the first problem was to increase the size of the sample of subjects selected for learning hierarchy evaluations. White suggested that problem two could be best solved through more careful introspection during the generation of a learning hierarchy candidate. However, no clues were given on how to detect this problem during the evaluation phase of learning hierarchy research.

Problems three and four are related. The use of only one question per element does not allow the estimation of the error in measuring the dependency among elements. Moreover, none of the existing dependency indexes reviewed by Capie and Jones (1971) make the concept of error of measurement explicit. Also, White (1974b) charged that indexes such as Gagné and Paradise's (1961) proportion of positive transfer as well as varients of it proposed by Walbesser and Eisenberg (1972), Guttman's coefficient of reproducibility (used in Resnick & Wang, 1969), and the four-fold contingency table and related phi correlation coefficient suggested by Capie and Jones (1971) share a common problem: each of these indexes can have values that indicate a hierarchical connection even when the skills are really independent.

White and Clark (1973) introduced a statistical test of hierarchical dependency which they purport treats the problem of error or measurement and also allows the inference of hierarchical dependencies among objectives for some population of interest. White and Clark carefully discussed the power function for this significance test in their Psychometrika paper. Unfortunately, White failed to discuss power issues in subsequent articles aimed at less technically sophisticated audiences. And it is precisely these audiences which repeatedly fail to recognize relationships between sample size and the power of significance tests in their research work (see Meehl, 1967). Consequently, educationally valid connections among elements in a hierarchy may, and probably will, be rejected if standard Neyman-Pearson hypothesis testing procedures are used in experiments with large samples of subjects that White also suggested. This point must be explained to practical research workers.

To solve the fifth problem, White advocated the administration of test items at key points during a learning program designed to teach the subject matter in the hypothesized sequence under consideration. Then, White and Clark's significance test may be applied to determine whether dependencies exists among elements in a posited hierarchy. Of course, this raises a fidelity issue: Does it make a difference that the hierarchy under consideration may not ultimately be used to sequence a learning program? Perhaps this question merits investigation.

The statement of White's sixth problem seems to be a reaction to blind, "dustbowl" empiricism in learning hierarchy research. White claimed that learning hierarchies modified on the basis of evaluative information should also be required to make logical, intuitive sense. If this is so, then what purpose does the evaluation serve and how are decisions to be made with an appropriate mix of logical and empirical information? On the other hand, unexamined learning hierarchies may have an intuitive appeal but may also seriously lack empirical import. As has already been asserted in this paper, the explication of decisions and decision-making strategies for the improvement of learning hierarchies would be a noteworthy contribution to the literature.

Concluding Remarks

The need for an empirically defensible means of sequencing instruction appears to have been the primary motivator for research into learning hierarchies. Four methods for generating candidates for learning hierarchies were reviewed: introspection, formal analysis, observation, and statistical "fishing". Experimental transfer of training studies and statistical studies have been used to evaluate posited hierarchies and significant modifications of these standard evaluative methods have been suggested to improve the internal validity of research into learning hierarchies.

Would the study of learning hierarchies have been important if a researcher with Gagné's stature had not chosen to become involved? Of course, an equally valid question is whether learning hierarchy research would have been discovered or received any creative impetus without his involvement? More generally, are topics in instructional science researched because of the importance of their patrons or are they studied for their intrinsic importance? Unraveling the answers to these questions may serve to demystify the study of learning hierarchies and lead to the statement of several critical questions for the future of learning hierarchy research.

Could we trim away our interest in learning hierarchies and, thereby, achieve a more parsimonious instructional science? Could we conduct the teaching/learning enterprise without learning hierarchies? Would any instructional sequence be better than none at least as good as one suggested by resource-consuming learning hierarchy research? Answers to these crucial questions, and others, may contribute evidence for determining the external validity of learning hierarchy studies. Perhaps, these questions are just as important as the present exclusive and pervasive interest in the internal validity of learning hierarchy experiments which has been reviewed in this paper.

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