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ABSTRACT

This document discusses how the organization of instruction influences the encoding and structuring of new material in the memory and the subsequent transfer of such information to novel situations. A theory of instruction for problem solving that considers relevant cognitive variables and that specifies the conditions for productive learning is described. First, an historical introduction to productive learning is presented including reference to the Gestalt problem solving literature, meaning theories of arithmetic instruction, and the discovery learning issue. Second, productive learning is defined and the basic external and internal (cognitive) variables are identified. Third, a theoretical framework for discussing productive learning based on the concept of assimilation is forwarded. Fourth, results are given from a series of experiments in which a meaningful context for instruction was presented either before or after the introduction of technical information to research subjects. The assimilation theory predicts that subjects in the "before" groups should be more likely to engage in productive learning since they have a meaningful context available during learning into which new information may be assimilated. Results from these experiments generally uphold the prediction. (Author/MM)

Effects of Instructional Organization and Sequencing on Productive Learning

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Introduction

The concept of productive learning has had a long, albeit multifaceted, history in instructional psychology. The Gestaltists were the first to explicityly emphasize a distinction between two types of learning. For example, Wertheimer (1959) distinguished instruction that fostered "structural understanding" from instruction that involved "rote memory", Katona (1940) distinguished "meaningful apprehension of relations" from "senseless drill and arbitrary associations, and Kohler (1959) separated "insight" from "trial and error learning". Unfortunately, however, the Gestaltists never clarified their various distinctions, often confused differences in instructional method with differences in the subsequent problem solving behavior, and provided little or questionable empirical support for their claims.

The flavor of their distinction can be found in an example by Wertheimer (1959) suggesting two methods of teaching a learner to find the area of a parallelogram. One method emphasizes the geometric or structural property that the triangle on one end of the figure could be placed on the other end to form a rectangle. The other method emphasizes a sort of cook-book recipe of steps to calculate the area, namely drop the perpendicular and multiply its height times the length of the base ($A = h \times b$).

Although learners taught under both methods should perform equally well on criterion tasks involving finding the area of parallelgrams like the ones they were taught about, Wertheimer reported the students differed in their ability to transfer what they learned to new tasks. For example, the subjects who learned by "understanding" (the first method) were able to find the area of unusual parallelograms and shapes, and to recognize uncalculable situations, while the students who learned in a mechanical way (the second

method) would say, "We haven't had this yet." According to Wertheimer, only the first group showed "productive" learning and thinking.

In an example of memorizing digit strings, Katona (1940) claimed that learning by "understanding the structural relationships" not only improves the learner's ability to transfer but also improves the learner's ability to retain the information over time. One group learned the digit string, 581215192226, by understanding the structural pattern of "add 3, add 4" as indicated below,

5 (add 3) 8 (add 4) 12 (add 3) 15 (add 4) 19 (add 3) 22 (add 4) 26

while another group learned by "rote memorization" with the string organized as 581-215-192-226. Although both groups performed equally well on criterion tests of immediate retention, Katona reported that the first group remembered the string longer.

Because of their potential importance for the design of instruction, these examples provide a tantilizing invitation to education psychologists for serious study of productive learning. One early attempt to bring "meaning" to school learning of arithmetic was lead by Brownell (see Weaver & Suydam, 1972). For example, Brownell & Moser (1949) taught third graders to solve subtraction problems such as,

$$\begin{array}{r} 65 \\ -28 \\ \hline \end{array}$$

One group of several hundred children learned by using concrete objects to represent the numerals, e.g., these students were given sticks that could be put in bundles of tens; the other group learned in a "purely mechanical rote fashion" by being given the rules verbally without any further explanation. Although both groups could be taught to perform equally well on the given problems, the "meaningful" group -- the children who had learned with stick bundles -- performed much better on later tests with different problems.

Such results provided fuel for Brownell's argument that learning should be based on "full recognition of the value of children's experiences" and should be aimed at making "arithmetic less a challenge to the pupil's memory and more a challenge to his intelligence" (Brownell, 1935, p. 31). Unfortunately, we do not yet know what makes arithmetic and mathematics more meaningful, and most mathematics teachers must rely on their own intuitions. The problems with the "new math" are a more recent example that we do not yet have the base of research data to prescribe what are the "meaningful" concepts that underly children's understanding of mathematics.

During the 1960's the distinction between two types of learning took on the equally ambiguous form of a distinction between "discovery" and "expository" methods of instruction. Bruner (1961, 1963, 1968) has been a major proponent of the discovery method, although his papers have not included summaries of strong empirical support. Although often describing discovery both as an instructional method and as a desired outcome of learning, and although seldom empirically defining either, Bruner's preferred method of instruction is exemplified in a procedure proposed by Dienes.

Dienes's method of teaching children the concept of the quadratic equation involved allowing students to manipulate shapes of size "x by x", "x by 1" and "1 by 1" in such a way that the student could see that the area of a square with sides of length x was x^2, of sides $(x+1)$ was $x^2 + x + x + 1$, of sides $(x+2)$ was $x^2 + 4x + 4$ and so on. The discovery method shares with the Gestalt "learning by understand" the promise of superior transfer and retention performance by the learner.

Unfortunately, experimental studies of discovery have not been 100% clear. Ten years ago Wittrock (1966) pointed out that, "Many strong claims for learning by discovery are made in educational psychology. But almost

none of these claims has been empirically substantiated or even clearly tested in an experiment." Although the effects of discovery manipulations are now being incorporated into theories of cognitive processing during learning (Egan & Greeno, 1974), it is still too early to refute Wittrock's statement.

Variables in Productive Learning

I have cited these examples and given an admittedly selective history of the many paths of the "productive learning" movement in order to show that the recent resurgence of interest is not totally novel. I also have done this in an attempt to try to overcome some of the problems that have plagued us in the past. After nearly a half century of pious claims and lip service to the need for "productive learning", educational psychology has now developed to the point where careful, scientific research can be conducted. Clearly we do not need any more calls for a revolution in education without corresponding experimental evidence; we do not need more massive development efforts until we pay our "dues" in basic research; we do not need to think about how to apply the principles of "productive learning" without first establishing what those principles are. I am convinced that only a commitment to basic research on the processes and cognitive structures involved in productive learning will produce a theory of learning and instruction that is sufficiently broad and succesful to offer practical prescriptions. Further it seems to me that the exciting developments in cognitive psychology can only serve to enrich and benefit our search.

How can we define productive learning? For the purposes of the present paper, I propose a definition that takes both internal, external and performance variables into account. Productive learning thus has the following characteristics:

(1) Encoding. The presented material is assimilated to existing knowledge structures rather than being added "as-is" to memory.

(2) Outcome. The resultant learning outcome is an integrated structure because it involves both the presented material and the knowledge to which it was assimilated; the alternative is a rote structure that includes only the presented material organized in memory in the same way it was presented.

(3) Performance. Due to a more integrated learning outcome the productive learners should show superior transfer to novel situations while other subjects (with rote outcomes) should excell only on retention of presented information.

Certainly, productive learning may be considered a continuum rather than a dichotomy, and may have several levels of integration for any task.

What is needed at this point? As can be seen from the foregoing array of largely untested examples and claims, the following are needed:

(1) a clear defintion of the external features of instruction for productive learning (i.e. the external conditions for productive learning), (2) a clear understanding of the learner's internal encoding activity during learning and the structure of the outcome that results (internal conditions of productive learning), and (3) a set of observable performance measures for measuring the productive learning process and outcome (i.e. the performance measures of productive learning).

Table 1 summarizes some of the main variables that should be included in a theory of instruction for productive learning. I have broken down the variables into:

external variables, such as the method of instruction, the type of to-be-learned material, and the characteristics of the learner.

processing variables, such as the reception of the material by the learner, the availability of a meaningful learning set in the learner, and the activation of the meaningful learning set during learning (these are actually the cognitive conditions of meaningful learning).

encoding variables, such as whether the new information is assimilated to existing structures or simply added in isolated form to memory.

outcome variables, such as the amount of learning, the degree to which original associations are retained, and the degree to which new associations to existing material have developed.

performance variables, such as percent correct on recall and transfer tests.

Although external and performance variables are directly observable, the other variables refer to internal, cognitive events which can be measured only indirectly.

The present paper will provide data on series of diverse experiments that investigate mainly one aspect of the external conditions (instructional method) and more specifically, investigate only o ne dimension within the domain of instructional method. In particular, I will focus on differences in processing, encoding, outcome and performance variables due to whether information is presented in a PRIMER-FACT organization or a FACT-PRIMER organization. In this case, "fact" will refer a set of technical information that has an underlying structure not obvious to the novice learner (e.g., a non-base 10 number system, computer programming, a series of premises, inter-related

facts in text). "Primer" refers to a meaningful set of previous experiences that can serve as an aid in comprehending the fact (e.g., advance organizers are primers). The only manipulation to be considered is sequencing since all subjects are presented with the exact same material.

External variables. Many methodological problems stem from unsatisfactory definitions of the independent (instructional) variables. For example, many studies conceptually confuse productive learning as a method of instruction (independent variable) and productive learning as an end in its own right (dependent variable), or label external instructional variables in terms of the internal responses or behavior such methods are thought to evoke.

All too often, inadequate definitions have accompanied not only a confusing of independent and dependent variables, but also a lumping together of several variables into one. the meaningful-rote (or productive-reproductive) dichotomy as the major instructional variable is actually a family of variables; any serious attempt to investigate instructional method effects should recognize the many variables involved.

For purposes of the right side of Table 1, I will focus on only one aspect of the instructional method: theorganization of text for problem solving into Primer-Fact or Fact-Primer. The type of material to be discussed is technical problem solving information such as non-base 10 arithmetic systems, computer programming, a set of related premises, an inter-related set of facts in text. This material is potentially meaningful in the sense that it can be better comprehended by relating it to a learner's past experiences. We have not focused on the characteristics of our learners, except to assume. that our college subjects were capable of productive learning (if all the conditions were met).

Processing variables. In order to learn productively at least three internal processing conditions (see Mayer, 1975a) must be met:

Reception -- The learner must receive the to-be-learned material.

Availability -- The learner must possess a meaingful learning set to which the new material is assimilated.

Activation -- The learner must actively process the meaningful learning set during learning.

In the Primer Before treatment, the meaningful learning set is made available before learning so that it can be activated by the learner during learning. The Primer After treatment does not allow for availability and activation because the "fact" has been processed before the meaningful learning set is introduced. These hypothesized differences in the processing variables for the two treatment groups are shown in the right side of Table 1.

Encoding variables. Two different kinds of encoding processes are:

Assimilation -- The learner actively integrates the new material within existing cognitive structures.

Addition -- The learner adds the new material to memory so that it is isolated from other information in memory.

In the Primer Before treatment the encoding process can involve assimilation since a meaningful learning set is available and activated during learning; however, for the Primer After group the basic encoding process is addition. These differences, as hypothesized, are also summarized in Table 1.

Outcome variables. There have been many advances in cognitive psychology in measuring the organization of memory, particularly memory for meaning which can be called "semantic memory". No longer need the measurement of learning outcomes be confined to total amount learned. These advances in cognitive psychology, and the foregoing approach to productive learning both

suggest that we must do a better job at analyzing the structure (rather than simply the amount) of learning outcomes. When we ask, "What is learned?" instead of simply, "How much is learned?" I think we can develop much more useful and powerful theories of learning and instruction.

In previous papers (Mayer & Greeno, 1972; Mayer, 1975a) we have suggested several major dimensions:

amount of nodes -- How many new pieces of information were incorporated into memory?

internal connections -- How many of the original associations among pieces of information are retained in the learning outcome?

external connections -- How many new associations have been made between the new information and previously existing knowledge?

In addition, we can go beyond these variables to develop task specific models of the semantic memory underlying the to-be-learned information. New techniques for text analysis allow us to measure exactly which idea units are learned and which are not learned, and the order of recall might give some insights into how these pieces of information are organized. Several such attempts to precisely define the characteristics of meaningful as rote learning outcomes are presented in Mayer (in press).

In the present example, the Primer-Fact subjects would be expected to develop more integrated cognitive structures with more external connections and fewer internal connections relative to the Fact-Primer group. The Fact-Primer group would be expected to develop more rote outcomes, retaining the original internal connections but with very few external connections.

Performance variables. The most common measures of performance have been:

retention -- including immediate and longer term ability to perform the learned task, and

transfer -- including the ability to apply the learned material to new and novel situations both near to and far from the original examples. Others include savings in relearning, amount recalled, structure of recall, etc.

In the present example, the Primer Before group should excell on transfer problems due to the availability of an integrated learning outcome while the rote outcome of the Primer After group should better support retention of specific information that was presented (see Table 1).

Theories of Learning and Instruction

In a previous review of research on meaningful vs. rote instruction for statistics, I suggested three general theoretical frameworks for interpreting the results (Mayer, 1975a). Theory 1 (or the one-stage model) posits that the learning outcome is a function of the amount of information that is presented and attended to by the learner. For this theory the main question is, "Does the learner receive the information?" This theory ignores all of the "internal" variables in Table 1. In this theory, the order in which information is received should have no effect on the outcome of learning.

Theory 2, or the two-stage model, posits that more is learned if the learner poses the pre-requisite anchoring concepts. In addition to the question for Theory 1, this theory asks, "Does the learner have the pre-requisite anchoring knowledge?" This theory ignores the encoding and outcome variables in Table 1. Theory 2 predicts that more facts should be learned from the Primer-Fact organization than from the Fact-Primer organization if the primer serves as a needed anchor.

Theory 3, the three-stage model, posits that learning involves assimilating new knowledge to the learner's existing knowledge structure. An addition to the above two questions is, "Does the learner actively integrate the new facts with the existing pre-requisite knowledge?" Theory 3 predicts that a

broader or more integrated learning outcome should result from Primer-Fact organization allowing superior transfer performance; in contrast, the Fact-Primer organization encourages addition of information to memory as presented and could result in superior retention of the basic facts in their presented order. It is Theory 3 that most closely fits into a theory of productive learning as outlined in Table 1.

Sequencing of Primers and Facts in Learning Computer Programming

In order to provide examples of the proposed framework, I will discuss several studies carried out in our labs recently.

Transfer. In a recent series of experiments (Mayer, 1975b, 1976a) college subjects read a 10-page text concerning a simple computer programming language, and were presented with a model of the computer either before or after reading the text. In these experiments the model was intended to serve as a primer; the model presented the computer in familiar terms such as expressing memory as an eraseable scoreboard or execution of statements as going down a shopping list.

The results indicated that the Primer Before group performed better than the Primer After group on questions requiring far transfer (such as interpreting what a program would do) while the Primer After group excelled on questions closely related to the text (such as writing simple programs or statements). Theory 1 would predict no differences since both groups received the same material (albeit in different orderings); theory 2 would predict that the primer before group might learn more overall by virtue of having a "cognitive anchor" for encoding the incoming material. However, the results are most consistent with theory 3 in that qualitatively different learning outcomes were obtained. Apparently, the Primer Before group assimilated the material to a broader set of past experiences; this allowed superior transfer to new situations but may have caused some loss of the original organization.

Structure of recall. In a follow-up study conducted in our lab by Bruce Bromage, subjects were given the primer-text and text-primer treatments similar to above. Then subjects were asked to recall selected portions of the text.

Theory 1 predicts no difference in the recall protocols while theory 2 predicts that the Primer Before group might recall more overall. However, theory 3 makes some predictions concerning more detailed differences in the protocols: because the Primer-After subjects focus more on retaining the technical text exactly as presented they would be expected to retain the general organization of the original text section and to use many technical symbols (for address names, pointers, example statements, etc.). Because the Primer-Before subjects integrate the new material within their past experience they would be expected to use relatively more words than symbols (i.e. by putting the text in their own words) and to use a different wording and organization than the original text; in addition, there should be relatively more intrusions from the primer (i.e. more references back to the model). Based on these factors (organization, intrusions, symbols/words, rewordings) blind raters were able to correctly predict over 75% of the subjects into the two treatments ($p < .05$).

This result encouraged the idea that there were measurable, qualitative differences between the protocols of the two groups. The texts were analyzed into a hierarchy of idea units, and the protocols were then analyzed to determine the number of idea units recalled, the order of recall, the number of intrusions, summaries, errors, etc. Although the analysis is not yet complete, initial results indicate that the Primer After subjects tend to remember isolated facts involving computer symbols and example statements

while Primer Before subjects tend to remember the format of statements and the operations involved that rely on underlying concepts, tend to use more intrusions and more summaries. A subsequent discriminant analysis will help isolate those factors that best distinguish the two groups, and the discriminant function will be tested against a validation sample. In this way we hope to make another modest step toward isolating the structural differences between meaningful and rote learning outcomes.

Sequencing of Primers and Facts in a Deduction Task

In another task (Mayer, 1976b) subjects were asked to memorize a set of one-way connections such as, L to S, C to N, S to C, N to M, H to L, M to H, etc., and were given a primer for converting letters to cities (L = Los Angeles, C = Chicago, S = Seattle, H = Houston, N = New York, M = Miami) either before or after learning. In subsequent tests subjects were asked questions which required putting the links together such as, "How many links are there from L to H?". Although both groups were very fast on recognizing the learned links, the Primer Before group excelled on problems requiring long chains of inference.

These results are also most consistent with theory 3 in that the Primer Before subjects apparently acquired more integrated cognitive structures. Theory 1 would predict no difference for any of the problems, while theory 2 would predict superior performance for the Primer Before group on retention and transfer problems.

Sequencing of Primers and Facts in Learning from Text

Finally, I would like to summarize a project currently being carried out in our labs, concerned with the effects of priming on learning from an organized text. Subjects read four passages with each one giving information about the economy, politics, geography, and climate for an imaginary country.

The Primer was a sheet of paper divided into a 4x4 matrix with the country names across the top and the four characteristics listed down the side. One group received the primer for 60 seconds before and one group received the primer after reading the four passages. In a subsequent test, both groups performed quite well on recall of a specific passage, (e.g. Write all you can about country X) but the Primer-Before group performed far fewer errors than the Primer-After group on questions requiring integrating two separate passages (e.g., The dryness of country X is comparable to the ___ of country Z?).

Theory 1 would predict no difference between the groups since all had been ex posed to the primer by the time of the test; theory 2 predicts that the Primer Before group should be superior both on retention and transfer. However, again these results are most consistent with theory 3, in that the Before subjects seem to have acquired a more integrated cognitive structure that allowed subjects to go beyond the original presentation organization more easily.

Sequencing of Primers and Facts in Learning an Arithmetic System

In another study (Mayer, in preparation) subjects learned to count in base-3 number system (w, d, r, dw, dd, dr, dww, dwd, dwr, ddw, ddd, ddr, drw, drd, drr, rww) and a primer (or converting letters to numbers (w=0, d=1, r=2) was given to subjects either before or after they learned to criterion. On a subsequent transfer test the Primer Before group excelled on transfer to new tasks such as counting beyond the original sequence or solving arithmetic problems.

Theory 1 would predict no difference between the treatments since all groups had the conversion list available for the test; theory 2 would predict that the Primer Before group might perform better overall. However, theory 3 is most consistent with the results of superior transfer for the Primer

Before group due to more integrated learning outcomes.

Summary

These results taken from different tasks and procedures share the same basic trend: Primer-Fact organization seems to lead to superior transfer performance (but not superior retention performance) as compared to Fact-Primer organization. Apparently, Primer Before treatments allow subjects to have meaningful learning sets available and active during encoding of the facts; this allows an assimilation process (rather than simple addition of information to memory) and results in a more integrated learning outcome.

The type of material used in all of these experiments was technical but it had an underlying organization that could be used to help comprehend it. I doubt whether similar results would be obrained for other types of material: for example, if the underlying structure and concepts are obvious the priming variable should have no effect; or if no true underlying concepts existed again priming would be of little influence.

These results fit nicely with the three stage model of learning, cited by Mayer (1975a), which could be called the "assimilation model". These results are also consistent with the increasing literature on priming effects of headings or titles on comprehension and memory for prose (see Schallert, 1976; Mayer, 1977). These results also provide one example of how internal events and conditions enrich our growing understanding of the psychology of instruction.

Footnote

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Table 1: Framework for a Theory of Productive Learning

Variables	Primer-Fact Sequencing	Fact-Primer Sequencing
EXTERNAL VARIABLES		
Method of Instruction	Primer-Fact	Fact-Primer
Characteristics of Material	Potentially Meaningful	Potentially Meaningful
Characteristics of Learner	College Novices	College Novices
PROCESSING VARIABLES		
Reception of Materian	Yes	Yes
Availability of MLS	Yes	No
Activation of MLS	Yes	No
ENCODING VARIABLES		
Assimilation or Addition	Assimilation	Addition
OUTCOME VARIABLES		
Integrated or Rote	Integrated	Rote
PERFORMANCE VARIABLES		
Transfer and Retention	Superior Transfer	Superior Retention