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ABSTRACT

A theory of learning and forgetting is proposed which uses an information processing (IP) model. The IP model views learning as a process of storing, retrieving, and outputing information from a permanent memory. The concept of information pattern is important to the IP model because the pattern of information determines how the information will be processed. The pattern is composed of those aspects of the impinging stimulus situation and the requirements of responding given by the learning task. It is suggested that the perceptual aspects of an information pattern are important in determining the storage location in the long term memory. Information patterns are stored in and retrieved from a specific address. The possibility of several addresses for the same information pattern may help account for forgetting: within a limited amount of time for a response only a limited number of searches can be made of the storage address system; thus the information may not be retrieved. The IP theory can account for output interference (inability to output recalled information): if the initial stimulus and elaborative information (which determine the address of the stored information) cannot be reconstructed, the information will not be retrieved. Educational implications of this theory are suggested and references are included. (AL)

# An Information Processing Theory of Learning and Forgetting

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Studies of interference in prose learning have been generated from one of two general theoretical approaches. Proponents of meaningful learning theory have pursued such studies in the attempt to show that interference phenomena such as retroactive or proactive inhibition (RI or PI) would not be found when meaningful materials are employed (Ausubel, 1963; Ausubel & Blake, 1958; Ausubel, Robbins & Blake, 1957; Ausubel, Staiger & Gaite, 1968). Interference theorists on the other hand have tried to demonstrate that RI and PI do occur with meaningful materials such as prose passages. It appears that the interference theorists have demonstrated their point. Retroactive and proactive inhibition do appear when prose materials are meaningfully learned (Anderson & Myrow, 1971; Myrow & Anderson, 1972; Crouse, 1970; Andre, 1971).

A point little noted in this controversy is that the mere demonstration of inhibition does not justify the conclusion that the interference model can explain forgetting. RI and PI are phenomena which may be explained by a variety of models or theories. The major contention of this paper is that neither the interference or meaningful learning models are adequate to explain the data on forgetting, and that an information processing (IP) model is needed.

This paper outlines some ideas about an information processing (IP) model of learning and memory which, I believe, provides a better fit to the data on forgetting than do the interference or meaningful learning approaches. The model is similar to other IP models such as the Atkinson-Shiffrin (1968) model. There are however, some important differences between the model discussed here and previously published models. The procedure followed in this paper will be to discuss the general components of the IP model, indicate its major differences from other models, show how it can handle data which presents problems for other models, discuss some predictions made by the model, and finally to present some educational implications of the model.

Basically the model views learning as the process of storing, retrieving, and outputing information from a permanent memory. Forgetting constitutes a failure of storage, retrieval, or outputing processes. Learning is assumed to be a unitary process, in the sense that the same principles apply to the learning of various types of materials. Thus the model does not postulate differences between rote and meaningful learning (Ausubel, 1963). The unit of learning is assumed to be the pattern. In many ways this concept is identical with what others have called a code, image, or ensemble of information (Atkinson & Whiffrin, 1968) or schema (Bartlett, 1967). Thus the model describes the storage, retrieval, and outputing of information patterns.

The concept of an information pattern is crucial to the understanding of the model. The model describes the principles by which information is processed. The particular patterns that constitute that information change as a function of the type of material to be learned and the requirements of the learning task. The pattern is composed of those aspects of the impinging stimulus situation and the requirements of responding as given by the learning task. This concept is discussed in greater detail below.

As in the Atkinson-Shiffrin (1963) model, the memory system is postulated to contain 3 logically separate memory stores or banks. The first of these consists of a very limited and short-term sensory register. Information in such a sensory register is in a relatively unprocessed state and is not required for any long period of time unless transferred into the second memory store, short term storage or memory (STM). As the operation of the sensory register is of little concern for this paper, it will not be discussed in greater detail. Atkinson & Shiffrin (1968), Neisser (1967), and Kumar (1971) provide a more detailed description.

Attended to sensory input is transferred from the sensory register to STM. This short term memory is conceived of as more than a memory store. It is in effect a working storage. Information in STM is being operated upon by the information processing system. Information may enter STM from either the sensory register or long term memory. Information in STM can be transformed, analyzed, or worked upon in various ways. In effect the STM concept is congruent with the notion of consciousness expressed in an earlier psychology. The operations performed upon information in STM can be considered the equivalent of thinking about the information. The operations of STM are of vital importance for this model.

From STM, information may be transferred to the third component of the memory system, long term memory (LTM). LTM is considered to be a permanent self-addressable random-access memory store. Once information is stored in LTM, it is never removed except through physical damage to the memory system. As Atkinson-Shiffrin (1968) point out, such a memory must be self- or content-addressable. In other words, the location or address of information in LTM must be determined by the content of the to-be-stored information pattern. Atkinson and Shiffrin suggest that a library cataloguing system provides an example of the operation of such a system. The content of a book determines its location in the library according to a prearranged cataloging strategy.

While suggestive of how the self-addressing system may work, the library model cannot adequately explain the operation of storage in LTM. Our best evidence suggests that the cataloging scheme in LTM is heirarchically organized according to a meaningful relationship between stimulus patterns. Yet it is obvious that the meaningful interpretation of a pattern depends upon reference to LTM. If LTM must be accessed to provide the meaning of a pattern, then the meaning of a pattern cannot solely determine the address of where it is stored.

I would like to suggest that the perceptual aspects of a pattern play an important role in determining the pattern's storage location in LTM. Thus visual characteristics, acoustic characteristics, contextual characteristics, and temporal characteristics seem to provide some of the important dimensions of determining a storage address. Such an interpretation is consistent with data from several sources. Paivio (1969) has shown that imagery plays an important role in learning and memory and further that in paired-associate learning, stimulus imagery value produces greater effects than response imagery value. Work dating back to Freud (1964) indicates that the sound characteristics of a word may be used to facilitate its recall. The contextual effects discussed by Dr. Jensen (1972) and others (Shand, 1970; Watts & Royer, 1969) are also compatible with a perceptual dimensions notion. Atkinson & Shiffrin (1968) discuss the role that temporal cues may play. Such a view also seems to be compatible with Pribriam's (1971) notion of a holographic type of storage.

The above discussion is not intended to suggest that meaningful relationships and interpretations of information patterns play no role in the computation of storage/retrieval addresses. It seems likely that the computation of addresses is a multiple-storage process. A preliminary address based upon the sensory aspects of the information pattern may be computed. Information may then be retrieved from this preliminary address, may then be used to modify the information pattern, and a new address may be computed for the new pattern. It is possible that this modification-computation cycle may be repeated several times in the course of learning a pattern.

The research on stimulus encoding, elaboration, or natural language mediation seems especially relevant (Adams & Montague, 1967; Mintsch, 1970). The implication of this research is that the input is modified or altered in the process of learning. What is learned is different from the presented stimulus. Such encoding processes may reflect the operation of the address computation system.

The address for storage of information also constitutes the retrieval address. In most learning tasks Ss are given information about the stimulus and response components of the tasks. In other words, the S is shown what aspects of the informational pattern will be given to him during tests and which aspects he will be expected to reproduce. It seems likely that the S computes the memory location using the stimulus aspects of the incoming pattern, and stores in that location information allowing him to produce the response. When instructions are not given as to which aspects of the information pattern will serve as the retrieval cue, the learning task should be more difficult. This prediction can account for the differential difficulty in learning unidirectional and bidirectional PA lists (Young, 1966) and may also account for the facilitative effect of giving Ss behavioral objectives (Mager & Clark, 1969). According to the model, a bidirectional list would be learned by storing the information pattern at two addresses. While such a list would be more difficult to learn, the model would predict that the list would be more resistant to retroactive or proactive inhibition. As far as I know, this prediction has not been tested. This is one direction for future research.

One important aspect of the model is that learned information is stored more than once. In explaining this it may be useful to trace the path of an item of to-be-learned information through the model. An item of information is first stored in the sensory register (SR). Upon transfer to STM, the processing system begins computing a storage address for the information. The address computation process occupies some period of time, so that subsequent items of information to be learned are stored in STM until they can be processed. Since most learning tasks present more items of information than can be stored in STM and the storage of information from STM to LTM requires more time than transfer from SR to STM only the first few items on the first trial manage to be stored in the first available location after the computed address. On subsequent trials the same address is computed and the item keeps being stored in the first available location after the computed address. This process results in multiple-storage of items in memory.

At retrieval some aspects of the original pattern are presented as a retrieval cue, a storage address is computed, and the system searches a block of storage addresses beginning with the computed address. On the basis of the information stored in this block of memory, the system attempts to compute or construct a response. If this is possible, the S responds. If this is not possible, no response is made and the S may try to search some other section of memory. However, in most learning tasks, the time requirements would limit the number of such searches that might be made. In addition, even when response time is not limited by the experimental procedures, the S may cease to search after a few tries. The number of searches is probably related to the criticalness or reinforcement value of locating the information.

The multiple storage and search of a block of memory have important implications for the study of forgetting. Postman (1963) has noted that interference theory seems to predict too much forgetting. Items that have been recalled several times during learning are less likely to be forgotten than items that have been recalled fewer times. If we assume that the number of recalls is indicative of the number of storages in LTM, then this finding is understandable. At retrieval, the S searches a block of memory of constant size and attempts to compute a response. If the number of storages has been enough to fill this storage block then the item would not be susceptable to interference. If the number of original learning (OL) storages has been insufficient to fill this block, then the block of memory will contain both OL and interpolated learning (IL) items. When the S attempts to compute a response from the contents of this block, the stored information does not allow him to compute a consistent response. Aspects of the OL and IL responses are stored in the block and the student cannot construct a possible response. Thus the model explains a phenomena that has been difficult for interference theory to handle.

This aspect of the current model is different from the Atkinson-Shiffrin formation. Atkinson and Shiffrin (1968) and Shiffrin (1970) have argued the interference is primarily a STM phenomena and consists of the failure of the system to search the appropriate locations of memory. While the present model includes this kind of forgetting, it also suggests that forgetting can also occur when the appropriate area of memory is searched, but the system is unable to compute an appropriate response from this area.

So far a model of memory has been outlined in which learning consists of the computation of storage addresses from the sensory aspects of a learning situation and the storage of the response attributes in these addresses. Nothing has been said about the storage of stimuli. It is known, however, that Ss learn stimuli in most P-A tasks as the literature on backward association amply demonstrates. Further it is known that stimulus recognition is an important precursor to associative learning. The S must recognize the stimulus in order to make the response (Martin, 1967a, b). If the model under discussion here is viable then it must be able to account for such data. What I would like to suggest is that stimulus recognition consists of the finding of response attributes in the memory block reference when the address is computed. Stimulus non-recognition occurs when the system fails to find any response attributes in the memory block so referenced. This assumption adequately accounts for the Martin (1967a, b) data, but says nothing about backward associations. In terms of the model, backward association is considered to be the incidental learning of an R-S association, in which the right hand term in a paired associate list is treated as a response. Such incidental learning occurs after the forward association is relatively well-learned. As the degree of learning of the forward association increases (the number of storages in LTM increases) the amount of time required to store a new copy in LTM decreases. Since items are presented for a constant amount of time, as the learning of an item increases the system is able to process information in new ways. The formation of backward association is one result of this processing. This interpretation leads to the prediction that backward association will be formed only for those items that are relatively well learned. Since the number of times an item is correct can serve as a measure of its degree of learning, the model predicts a correlation between this variable and the correct or incorrect recall of a backward association. This description seems to fit the facts of a backward association reasonably well. It is well known that Ss do not perform as well on tests of backward association as on tests of forward association. In other words, the Ss don't know as many backward associations as forward associations (Battig, 1967). While I know of no evidence on the matter, I am reasonably confident that the backward associations that are found are a function of the number of times a forward association is given correctly and further that unless the forward association is given the backward association will not be.

One phenomenon that presents difficulties for interference theory and meaningful learning theories is known as output interference (Tulving, 1966; Andre, 1971). Tulving, for example, found that if Ss were required to give repeated recalls in a free recall experiment, only 50% of the items were repeated from trial to trial. The remaining items were remembered on one trial but not on the others. In other words, there were items available for recall that were not output. Andre (1971) found evidence of such output interference in a prose RI situation.

The IP model can account for this phenomenon quite handily. Recall that the address of a to-be-stored item was computed from the stimulus and any elaborative material added from LTM retrieval of the item would depend on the reconstruction of the original address. This means that essentially the same elaborative material would have to be added during the retrieval processes. In other words, the S would have to reconstruct the same "mnemonic" device as used to store the material originally. On some recall trials the reconstruction would fail, on others succeed allowing such correct remembering.

Such an interpretation is supported by the research on the effects of retrieval cues in free recall. As several studies have shown, the addition of retrieval cues such as category names after the S has completed his original recall can lead to further recall by the S (Tulving & Pearlstone, 1966; Jung, 1967; Earhart, 1967; Allen, 1969). In terms of the model the retrieval cue would consist of an item added to the stimulus during learning that was not reconstructed during recall. Its presentation to the S allows him to compute the correct address and retrieve additional items.

One of the more interesting problems for interference theory are the differential effects of massed and distributed practice on forgetting. Despite equal "degrees of learning," information learned under massed practice is invariably more subject to RI or PI than information learned under distributed practice (Underwood & Ekstrand, 1966). The IP model can predict such results. Again the total stimulus situation at the time of learning determines the address of stored information. Contextual and temporal-historical cues play a role in the storage, since such cues remain relatively constant during massed practice but change during distributed practice, distributed practice should lead to storage of information in many different locations of memory whereas massed practice should lead to storage in only one location. When the S's memory is tested, storage in many locations means that the S is more likely to retrieve the information (access an appropriate memory block) than if the information is stored in only one location.

Some Educational Implications of the IP Model

It seems to me that there are two major areas of the model for which educational intervention may be appropriate. The first of these involves the cataloguing system that provides for storage into LTM. It was suggested previously that the self-addressing system works upon the perceptual aspects of a pattern and the meaningful interrelations or associations of the stimuli with other stimuli. This storing system is probably built up over time as the person learns more and more about the world. In other words, the developing person builds up a series of programs or procedures for storing information in LTM.

Many of the differences between individuals are no doubt due to the efficiency with which the storage-retrieval system works. Individuals who are able to store and retrieve information more efficiently and in a more organized manner should be more intelligent than individuals whose storage system is not so efficient. Since the storage system is developed out of the experiences of the individual, it is logical that by providing appropriate experiences the storage system should be improved.

The notion that information stored in memory is referenced through a heirarchically organized system or program is not very different from Ausubel's notion of cognitive structure (1963). What is different is that: 1) all information stored in memory is processed through the system (not just connected discourse) and 2) the interpretation of such a notion gives us a way to study the development of storage processes.

The second area where education may affect IP processes is that of the strategies and programs used in STM for processing information. It seems clear that the S can employ a variety of strategies for storing and retrieving information. For example, some of my unpublished work has shown that the new item priority effect is produced by a subject controlled processing strategy. Such processing strategies must also develop over time, probably as a function of experience.

What is needed is a series of studies to determine how this storage-retrieval process or system develops. The techniques used for studying such processes in adults gives us the beginnings of a method to attack this problem. New techniques may have to be formulated, but the already developed techniques give us a starting point. We need to pursue developmental studies in this area.

One of the major problems with objectives of education has been that while we can specify the behaviors of students who "know" the content of what we teach, we have been unable to specify just what are the behaviors of students who can "think." Yet teaching students to think has been one of the overriding goals of education. IP models provide the means to arrive at an operational definition of thought. The developmental study of human information processing will lead to the creation of educational programs designed to increase student's ability to think.

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