A Test of the Effectiveness and Efficiency of the Low-First Method Derived from a Reactivation Theory of Spacing Effects

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It has been demonstrated in a number of psychological experiments (e.g., Glenberg, 1979; Madigan, 1969) that spaced learning is more effective than massed learning. Without exception, however, the theories so far proposed to explain the cause of this spacing effect have been weakened by contradictions (Dempster, 1996; Greene, 1989; Mizuno, 1996). Even the most promising encoding variability theory, which assumed that encoding differences in repeated events would improve memory (e.g., Madigan, 1969), was later controverted by experimental results indicating that repeated presentation in the same context facilitated memorization better than in a varying context (Postman & Knecht, 1983), or showing that the manipulation designed to affect the number of retrieval routes had no independent influence on spacing effects (Dempster, 1987).

Then Mizuno (1996) proposed a reactivation theory of spacing effects which offered a coherent explanation for these experimental results. This theory assumes that spacing effects are caused by the large reactivation on relearning of memory representations which have decayed within the spaces. The basic validity of this theory was verified by Mizuno (1998a) by conducting several priming and recall experiments with spaces as independent variables to find that there was a correlation between reactivation and recall rates. Mizuno (1997a) then made a model of activity change in memory representation based on the experimental results and conducted simulations to find that the correlation between reactivation and recall rates was not linear but logistic. She then constructed a reactivation model expressing the activity change in memory representation and the logistic correlation between reactivation and recall rates. Mizuno (1998b) next conducted several experiments increasing the number of presentations to find that the decrease in speed of activation decay depended not on the increase in the number of presentations but on the increase in reactivation on learning. Consequently, she revised the reactivation model and verified its validity by comparing the results of simulations with the previous experiments (Mizuno, 1997b). The essential equations for the completed model, those relating to activation change and the logistic correlation between recall rates and reactivation, are shown below.

\[ \text{act} = a \cdot t \cdot \exp \left( -t \cdot \text{cum}_\text{react} \right) \]  
\[ \text{cum}_\text{react} = \sum w_i \cdot \text{react}_i \]  
\[ w_i = \eta \cdot 2^{-(N-i)} \]

\[ Pr = \frac{\delta}{1.0 + \exp \left( -\text{cum}_\text{react} \right)} \]  

Pr: probability of recall  
\( \delta, \eta, \alpha, \theta \): parameters

A reactivation theory with such a concrete model enables us not only to identify the cause of spacing effects but also to make specific predictions concerning the size and the processes of occurrence of spacing effects under hypothetical conditions and, above all, to answer fundamental questions about what kind of spaced learning schedule would be the most effective.

According to the model, when the reactivation (strictly, \( \text{cum}_\text{react} \) in Equation (1)) of a memory representation at learning was small, that is, when recall rate was low, the next space should be relatively small to obtain sufficient reactivation at the next learning because the speed of activation decay will be fast (see Figure 1, A). On the other hand, when the reactivation at learning was large and recall rate was high, the next space should be relatively large because the decay speed will be slow (see Figure 1, B). These
considerations led to the prediction that the largest spacing effect could be obtained when the space between repeated items was determined according to the reactivation, that is, recall rate.

However, it would have been substantially impossible to set the spaces between all the items to be learned according precisely to this prediction because the most advantageous presentation positions for some items would overlap. This would have been even truer if the number of items or the repetition times of learning had been increased.

So the author devised a practical and effective new spaced learning method applicable to any sequential learning irrespective of the number of items or repetition times, and at the same time consistent with the prediction derived from the reactivation model. The name given to this method is "the Low-First Method".

The first principle of this method is as follows. In the first session, all the items are learned sequentially in an arbitrary order. Then, they are sorted by their weighted cumulative recall rates, \( P_n \) (Equation (3)), in ascending order, for the subsequent learning session. This procedure is repeated at the end of each of the following sessions. If \( P_n \) for several items are the same, their relative positions remain unchanged.

\[
P_n = \sum_{i=1}^{n} 2^{-(n-i+1)} p_i
\]

\( P_n \): weighted cumulative recall rate of an item after the \( n \)th session
\( n \): number of present session
\( p_i \): recall rate of the item in the \( i \)th session

\( P_n \) is, so to speak, an index of the degree of memory consolidation at any given point. The reason why a more recent recall rate should have more weight is because it has been found that more recent reactivation has a greater effect on the final recall rate (e.g., Mizuno, 1997b). This method of weighting was also based on the idea that memory is more consolidated in a case where successful recall occurs after a failure to recall than in the reverse case where failure to recall follows successful recall.

With this procedure, the items with low recall rates are presented after a relatively short time and those with high recall rates after a relatively long time, which should enable all the items to be presented with the most advantageous spaces possible, thus resulting in effective learning.

The second principle of this method is to omit items whose \( P_n \) was equal to or more than 0.75, corresponding to the case in which an item was successfully recalled twice or more in succession (Mizuno, in press). With this procedure, learners do not need to relearn remembered items unnecessarily and learning should therefore be more efficient.

An experiment was conducted to test the effectiveness and the efficiency of this Low-First Method

\textbf{Method}

Four conditions (2 (with or without the first principle) \& 2 (with or without the second principle)) were established to examine the effects of the two principles separately. The four conditions have been labelled C (control), F (first principle only), S (second principle only), and B (both principles).

\textbf{Participants}. Eighty freshmen, who were unfamiliar with English psychological terms, participated in the experiment. Participants were allocated randomly to the four groups.

\textbf{Materials}. The experimental materials in a learning session consisted of 12 psychological terms in Japanese which functioned as cue words and a corresponding set of 12 English response expressions (see Table 1).

\textbf{Procedure}. The experiment was conducted using CGI programs written in Perl and HTML scripts. Participants were tested individually. They were told to recall the English expressions in response to the Japanese cue words. Each Japanese cue was presented one by one on the Web browser, and the participants recalled the corresponding English expression and entered it in the space below (see Figure 2). The word
"Correct" appeared and a chime was heard when the answer was correct. The word "Wrong" and an alarm signaled a wrong answer and the correct answer was then displayed. On clicking "Next", the subsequent item was presented. At the end of each learning session, the number of correct responses was shown. The presentation order for the next session remained the same for group C, but was rearranged for groups F, S, and B according to the first principle only, to the second principle only, or to both principles, respectively.

Participants repeated the learning session a total of four times using this procedure. After the set of four learning sessions, 10 simple arithmetic problems were given as distracting tasks, followed by a test of the 12 items.

Results and Discussion

Table 2 shows examples of the learning process in two participants chosen at random, one from group C and the other from B.

Scores. First, the mean scores in the first learning session for the four groups were compared to see if there were any significant differences in the participants’ original knowledge of English. The mean scores (SD) for groups C, F, S, and B were 1.55 (0.89), 1.45 (0.83), 1.50 (0.83), and 1.65 (0.75), and a 2 (with or without the first principle) ¥ 2 (with or without the second principle) ANOVA showed neither significant main effects nor interaction (F(1, 76)=0.02, 0.17, 0.46, all ns, MSe=0.677), indicating that the Low-First Method is effective, and that this was owing mostly to the first principle.

Numbers of Errors. First, the data for groups C and F were examined to see if, against the assumption of the second principle, the participants had failed to recall after having succeeded in doing so twice in succession. Total occurrence of this type of failure was only 5 for group C and only 2 for group F. This result was regarded as negligible. However, lest the following analysis of the total number of errors should be unfairly influenced, these numbers were subtracted from the total numbers of errors of participants in advance.

The mean total numbers of errors are shown in Figure 4. A two-way ANOVA showed a significant main effect for both the first principle (F(1, 76)=199.52, p<.01, MSe=5.089) and for the second (F(1, 76)=44.77, p<.01), and also a significant interaction between the two (F(1, 76)=11.69, p<.01). Analysis of the simple effect of the second principle revealed that there was no significant difference between groups C and F (F(1, 76)=5.35, ns). This was not the case, however, for groups S and B (F(1, 75)=51.11, p<.01). These results indicated that although both the first and second principles led to a
decrease in the number of errors, it was when the first principle had been combined with the second that the Low-First Method had resulted in the least errors.

**Learning Times.** The mean learning times for the four groups are shown in Figure 5. A two-way ANOVA was conducted to find that the main effect of the first principle was not significant ($F(1, 76)=3.34$, $MS_e=1.09$, $ns$), but that the main effect of the second principle ($F(1, 76)=15.42$, $p<.01$) and their interaction ($F(1, 76)=4.86$, $p<.05$) were significant. Analysis of the simple main effect of the second principle revealed that there was no significant difference between groups C and S ($F(1, 76)=1.48$, $ns$), but that there was between groups F and B ($F(1, 76)=18.81$, $p<.01$), indicating that the second principle alone did not shorten the learning time, and that the learning time for the Low-First Method which combined the first principle with the second was the shortest of all.

All these results together suggest that the revised Low-First Method, combining the first principle with the second, is not only effective but also highly efficient.

**Conclusion**

The Low-First Method incorporating the two principles was shown to be very effective. It was also found to be essential to combine the first principle with the second principle to make it a smooth and efficient procedure.

Spaced learning might indeed be more effective than massed learning. But it necessarily entails repeated learning of the same series of items even if they are numerous, which is hard and boring. Moreover, in such a spaced learning based on mere repetition, it sometimes happens that learners remain forever unable to recall some items and that those items that can be recalled are always recalled.

The Low-First Method proposed here will certainly solve these problems. It does not oblige learners to relearn remembered items more than is necessary. It enables them to concentrate only on the unremembered items presented with the most advantageous spaces possible and thus to remember those items more securely and efficiently.

Now it is desirable and necessary to test the validity of the Low-First Method by applying it in such educational practices as questioning, presenting tasks, and above all, CAI which, despite the lack of any convincing scientific foundation, has flourished recently, and is actually well suited for this kind of repeated spaced learning.

**References**


