Implementing optimal spaced learning for English vocabulary learning: Towards improvement of the Low-First Method derived from the reactivation theory

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The spacing effect is known to be one of the most robust phenomena in experimental psychology, and many attempts have been made to realize effective spaced learning for L2 vocabulary learning. This study, by incorporating structural elaboration as corrective feedback, attempts to improve a computer program for L2 vocabulary learning based on the Low-First Method, an algorithm which was developed to realize optimal spaced learning. The present experiment revealed that although structural elaboration did not contribute to effectiveness or time-efficiency, it significantly decreased the number of errors during learning. The effects of corrective feedback were also found to interact with individual differences in learners.

Vocabulary knowledge constitutes an integral part of learners' general proficiency in a second/foreign language (L2) and is a prerequisite for successful communication (Nation, 2001). Research on vocabulary acquisition demonstrates that systematic rehearsal is essential for effective vocabulary learning. Rehearsal is defined as an activity to encode new information into our long-term memory through overt or silent articulation (Hulstijn, 2001). Unless they are rehearsed frequently, most new words will eventually be forgotten no matter how deeply they are processed at the first encounter due to the fragile nature of human memory (Ellis, 1995; Hulstijn, 2001; Nation, 2001).

In rehearsing lexical items, how to distribute rehearsal opportunities affects the effectiveness and efficiency of the learning activities. This paper investigates a computer program based on the Low-First Method, an algorithm which was advanced in cognitive psychology in an attempt to realize the most optimal scheduling of rehearsal opportunities, and aims to improve its effectiveness and efficiency for L2 vocabulary learning.

1 Literature review

1.1 The spacing effect and L2 vocabulary learning

Scheduling of rehearsing opportunities is usually divided into two types: spaced learning and massed learning. In spaced learning, rehearsal activities for a given item are spread over a longer period of time while in the latter, they are condensed into a smaller number of sessions. For a given amount of study time, spaced learning yields significantly higher recall rates than massed learning, a phenomenon referred to as a spacing effect (Baddeley, 1997; Hulstijn, 2001; Mizuno, 1996, 2003b).

Ellis (1995) notes that "[t]he spacing effect is one of the most robust phenomena in experimental psychology" (p.118). The effect has been unanimously supported by numerous psychological experiments since its discovery in the 19th century (Baddeley, 1997; Bahrick & Phelps, 1987; Ellis, 1995; Hulstijn, 2001; Mizuno, 1996, 2003b; Nation, 2001). Spaced learning is normally twice as effective as massed learning, and the effect is found for learning involving a wide range of materials from visual to verbal information including L2 words (Ellis, 1995; Mizuno, 2003b). The spacing effect also sustains over a relatively long period of time: Bahrick and Phelps (1987) observed the superiority of spaced practice eight years after learning.

In view of the reliability and significance of the spacing effect, many attempts have been made to realize effective and efficient spaced learning in the field of L2 vocabulary learning. Most studies have examined computer-controlled sequencing algorithms because computers can optimize scheduling of rehearsal opportunities by keeping a record of the learner's performance on individual words and presenting the words that need to be rehearsed most at the time (Ellis, 1995; Hulstijn, 2001; Nation, 2001). The weakness of the previous studies is that they have aimed to implement an effective spaced learning schedule without understanding the very cause of the spacing effect. Although the spacing effect has been extensively studied for more than a century (Baddeley, 1997), an explanation for its cause had not been agreed upon until the reactivation theory of spacing effects was proposed (Mizuno, 1996, 1998, 2003b).

1.2 The reactivation theory and the Low-First Method

The reactivation theory attempts to explain the cause of spacing effects in terms of changes in memory reactivation. In spaced learning, it is discovered that memory reactivation at the subsequent learning trial is larger than in massed learning. Mizuno (1996, 1998, 2003b) hypothesized that it was these changes in memory reactivation that caused the spacing effect, which has been consistently supported by her subsequent experiments. Based on the predictions made from the theory and experimental results, Mizuno (2003a, 2003b) constructed a model consisting of equations to express changes in memory activity and a relationship between memory reactivation and the probability of recall. The reactivation theory is significant not only because it adequately explains the cause of the spacing effect but also provides us with the concrete model, from which we might be able to work out the optimal spaced learning schedule (see Mizuno, 2003b, for details about the reactivation theory).

Based on predications made from the reactivation theory and the resulting model, the Low-First Method has been developed to realize effective spaced learning. The method, which consists of three principles, is the first algorithm to base itself on thorough understanding of the spacing effect (see Mizuno, 2003a, for details about the algorithm and its three principles), and its effectiveness has been consistently confirmed by a number of experiments (Mizuno, 2000, 2001, 2002a, 2002b, 2003a, 2004). Nevertheless, since the method was developed out of purely theoretical findings in the realm of cognitive psychology, it still suffers from a number of limitations and needs certain modifications to be useful for real-life L2 learners.

For example, Nakata (2006) argued that the effectiveness and efficiency of the program could be improved by modifying the feedback given to an incorrect answer. In all the studies on L2 word learning based on the Low-First Method, the subjects are required to type an English word from the equivalent Japanese translation as a cue. In order to successfully retrieve the English word, therefore, the subjects need to acquire not only the word form-meaning connection but also the correct spelling of the word. Nakata (2006) claimed that the corrective feedback used in Mizuno's studies, which required learners to take a look at and confirm the correct English word (Figure 1), might be useful for strengthening the word form-meaning mapping, but not necessarily facilitate acquisition of the spelling.

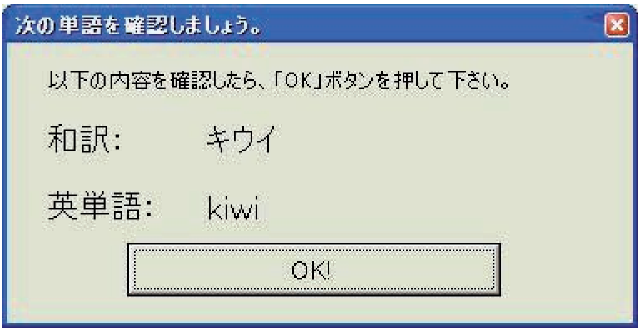

Figure 1. A replication of corrective feedback in Mizuno's studies

The rationale for his argument is that the feedback does not require *structural elaboration* on the part of learners'. Structural elaboration is defined as the "increased evaluation of an item with regard to its (phonemic, graphemic) structure" (Barcroft, 2002, pp.323-324). Examples of a task requiring structural elaboration are counting letters in a word, crossing out vowels in a word, or copying a word (Barcroft, 2002; Thomas & Dieter, 1987). Previous research shows that acquisition of the word form is facilitated by such tasks (Barcroft, 2002; Thomas & Dieter, 1987).

Nakata (2006) hypothesized that the Low-First Method would be more effective and efficient if structural elaboration were incorporated into the corrective feedback, providing a new kind of feedback. In his new feedback, the subjects were requested not only to take a look at but also to type the correct English word in a white box in a pop-up window (Figure 2). Unless they successfully did so, they could not proceed to the next item. In order to investigate the effects of the two kinds of corrective feedback, Nakata (2006) empirically examined learning with the Low-First Method under two conditions: a condition with structural elaboration as corrective feedback (Figure 2) and a one without (Figure 1). He named the former condition +*structural* condition and the latter -*structural* condition. His experiment revealed that contrary to his predictions, the +structural condition improved neither effectiveness nor efficiency: although the +structural condition required significantly longer study time, the differences in the immediate or delayed posttest scores between the two were not significant.

Figure 2. The new type of corrective feedback in Nakata (2006)

2 Hypotheses

The aim of the present study is to replicate Nakata (2006) to see if the results obtained by him will be reproduced. The following three hypotheses, which were the focus of the earlier study, will be examined:

- Hypothesis I: The +Structural condition will be more efficient than the –structural condition.
- Hypothesis II: The +Structural condition will be more effective than the –structural condition.
- Hypothesis III: The +Structural condition will be evaluated more highly by learners than the –structural condition.

Hypothesis I concerns the efficiency of each condition. In the Low-First Method, efficiency is measured by two dependent variables: *access times* and *study time*. Access times refer to the total number of times that the computer program tests target items before the learning session is completed while the study time is the amount of time the learner needs to complete the learning session. Fewer access times and less study time are interpreted to indicate more efficient learning.[1] It will be hypothesized that +structural condition will result in significantly fewer access times and less study time than the –structural based on findings from Thomas and Dieter (1987) and Barcroft (2002). These two studies demonstrate that elaborate processing of structural properties of a word facilitates acquisition of its spelling. The +structural condition in the present study is expected to aid learners in acquisition of word forms and to decrease the number of spelling errors during learning, leading to a lower number of access times and less total study time compared with the –structural condition. In Nakata (2006), the +structural condition resulted in fewer access times than the –structural as predicted, but the difference fell short of statistical significance ($p < .10$). He also observed that, unexpectedly, the words studied under the +structural condition required significantly more time (10.73 seconds per word) than those under the –structural condition ($p < .001$), rejecting Hypothesis I. With the discrepancy between the hypothesis and the results reported by Nakata (2006) in mind, the present study aims to test this hypothesis with a larger population (66 subjects as opposed to 38 in the former study).

Regarding Hypothesis II, I will use scores on immediate and delayed posttests as an index of each condition's effectiveness. This hypothesis expects that the +structural condition will increase not only the efficiency but also the effectiveness of the Low-First Method by drawing the learner's attention to orthographical features of target words through structural elaboration. In Nakata (2006), average scores under the +structural and the –structural conditions (with standard deviations in parentheses) were 4.32 (0.67) and 4.24 (0.95) on the immediate posttest and 1.08 (0.98) and 0.98 (0.89) on the delayed posttest (the possible maximum score is five for each condition), and no significant difference was detected between them on either test. Considering the relatively low scores on the delayed posttest, it might be possible to speculate that the memory for the target items had decayed so much by the time of the test that we could not detect subtle differences between the two conditions. In this experiment, therefore, I have decided to give the delayed posttest four days after the treatment instead of a week and investigate whether the results yielded by the earlier study will be reproduced.

The first and second hypotheses lead to the third one. Learners will prefer the +structural condition to the –structural because it will be natural for them to favor a condition which is more efficient and effective. If Hypothesis III is supported, it will follow that the +structural condition has a more positive effect on learners' motivation because forcing learners to study in a condition that they do not like will have a negative effect on their motivation. Nakata (2006) found that in a questionnaire administered after the learning session, 36 out of the 38 learners (94.7%) replied that they perceived the +structural condition to be more helpful for learning. The overwhelming support for the +structural condition is expected to be replicated in this study. If some learners are found to deviate from the majority of learners and do not exhibit a preference for the +structural condition, their learning outcomes and other variables such as their English proficiency and familiarity with computers will be analyzed to identify possible factors that contribute to the variations in feedback preferences.

3 Method

3.1 Participants

The participants were 66 first- or second-year high school students. The subjects were assigned either to Group A or Group B so that there would be no significant difference in scores on the GTEC Test for Students, $t(64) = -0.28$, *ns*. The type of corrective feedback was a within subject variable, and the two groups experienced different kinds of feedback for different sets of words (Table 1). [2]

Table 1: Feedback assignment for Group A and B

	Items X	Items Y
Group A	+Structural condition	-Structural condition
Group B	-Structural condition	+Structural condition

Note. Items X = *grig, saliva, antic, cavity*, and *dike*, Items Y = *toil, loach, sentry, mane*, and *debris*.

3.2 Procedures

Firstly, a pretest was administered to ascertain whether the participants had any prior knowledge of the target words in the experiment. After the test, the subjects studied 10 English words using the same computer software used in Nakata (2006), which was programmed by him to replicate the Low-First Method. In the program, the subjects were presented with a Japanese translation as a cue and required to type the corresponding English word. If they typed a blank or incorrect response, corrective feedback was automatically presented. The program displayed different types of corrective feedback to words studied under the –structural condition (Figure 1) and the +structural condition (Figure 2). See Appendix A and B for the source codes of the –structural and the +structural conditions. The study session ended when all the 10 items reached the retirement criterion determined by the second principle of the Low-First Method (Mizuno, 2000).

Following the study session, the participants answered 10 two-digit additions as a distractor task. This task was included to faithfully replicate Nakata (2006) as well as Mizuno's original studies. Shortly after the distractor task, the subjects took the immediate posttest. They were required to recall the 10 target English words from Japanese translations. After the posttest, the subjects filled in a questionnaire, which requested them to evaluate the computer program used in the experiment and give some background information about themselves. Finally, four days after the study session, an unannounced delayed posttest was conducted. The test was the same as the immediate posttest except for the order of the items. In scoring the posttests, any misspelling was regarded as an incorrect answer, and no partial credit was given.

4 Results

4.1 Learning outcomes under +/–structural conditions

On the pretest, no one exhibited prior knowledge of any of the target words. Since feedback types for target items were counter-balanced between Group A and B students (see Table 1), and their English proficiency and prior knowledge of target words were controlled, it is assumed that the different outcomes obtained under the two conditions resulted solely from differences in feedback types. Table 3 in Appendix C summarizes and compares the average access times, study time, study time per access time (henceforth time/access), and posttest scores for words studied under +structural and –structural conditions.

In Table 3, the large standard deviation of the number of access times in the –structural condition, i.e., 16.47 as opposed to the mean, 29.83, calls for particular attention. A close examination of the data revealed that there were four learners whose access times in the –structural condition were greater than two standard deviations above the mean (66, 69, 97, and 110, respectively). By contrast, the top four largest access times in the +structural were 38, 41, 47, and 57. It looks as if learning under the –structural condition proved extremely inefficient for some learners while the +structural condition decreased errors successfully for most participants. Since their presence invalidates the use of a parametric *t* test, the four outliers were excluded from the following statistical analysis. As these four subjects were comprised of three Group A and one Group B participants, two Group B subjects with largest access times in the +structural condition (37 and 47) were also dropped to obtain an equal number of subjects in each group. For the remaining 60 participants, the differences in their performance were compared with two-tailed paired *t* tests to evaluate the two conditions' effectiveness and efficiency (Table 2).

Table 2: Learners' performance in +/–structural conditions (without outliers)

		+Structural		–Structural		Paired t tests		
	n	M	SD	M	SD	df	t	
Access times	60	24.33	5.69	26.00	6.93	59	-2.55	*
Study time (sec.)	60	277.35	108.67	227.52	98.07	59	4.93	***
Time/access	60	11.36	3.44	8.81	3.59	59	8.72	***
Immediate posttesta	60	4.35	0.84	4.27	0.97	59	0.71	
Delayed posttesta	55	1.89	1.42	1.93	1.33	54	-0.22	

Note. [a] The possible maximum score is five for each condition.
*** $p < .001$. * $p < .05$.

As predicted by Hypothesis I, average access times for the +structural condition were significantly smaller than those for the –structural, which suggests that structural elaboration successfully reduced errors during learning and allowed learners to complete the learning session more smoothly. Unexpectedly, the +structural condition significantly increased not only the time/access but also the total study time: the condition required 49.83 seconds more than the –structural on average, and the hypothesis about the study time was refuted. Contrary to Hypothesis II, there were no significant differences in the immediate or delayed posttest scores. In short, except for the difference in the p values for access times ($p < .10$ for the former and $p < .05$ for the present study), the overall findings in this study were consistent with those reported by Nakata (2006), implying that the +structural condition was neither more time-efficient nor effective than the –structural condition. The reasons for the discrepancies between the hypotheses and results will be considered in the first part of the discussion section.

4.2 Evaluation by learners

In the questionnaire administered shortly after the immediate posttest, the subjects were requested to indicate which feedback they found the more helpful for learning. It turned out that 46 out of 65 learners (70.8%) favored the +structural condition, seven (10.8%) found the –structural condition more desirable, and the other 12 (18.5%) chose the option "Either one is OK" (they will be referred to as *+Structural*, *-Structural*, and *Either* learners, respectively).[3] With regard to their group assignments (Table 1), Group A and Group B subjects were almost evenly distributed across the three groups: while 23 +Structural, six Either, and four –Structural learners were from Group A, 23 +Structural, six Either, and three –Structural students came from Group B. All of the four outliers identified earlier were among +Structural subjects.

The participants were also requested to give reasons for their feedback preferences, and 40 +Structural, six Either, and six -Structural subjects provided an answer. Analysis of their comments revealed stark contrasts between the three groups (selected excerpts from the learners' comments are presented in Appendix D). All of the 40 +Structural learners observed that typing English words helps memorization better than just looking at them. Four of them explicitly mentioned their dissatisfaction with the –structural condition. By contrast, none of –Structural learners noted that the –structural condition facilitated learning. Rather, they seemed to prefer the –structural condition because they felt that it was quicker or easier than the +structural. Those who chose the "Either" option replied that they did not perceive much difference between the two conditions.

With the majority evaluating the +structural condition more highly, the results constitute support for Hypothesis III. However, the reason why only +Structural learners perceived the facilitative effect of the +structural condition and the other types of learners did not requires further investigation. The possible factors that might have contributed to the variations in feedback preferences would be the differences in (1) their performance under +/–structural conditions, (2) their English proficiency, and (3) their familiarity with computers. The remainder of this section will attempt to describe the profiles of +Structural, Either, and –Structural subjects in relation to these three variables.

Firstly, in order to examine whether structural elaboration had different influence on the three groups, their performance under the two conditions were analyzed separately and compared with two-tailed paired t tests (for +Structural learners) or Wilcoxon's signed-ranks tests (for Either and –Structural learners). The four outliers in +Structural group were deleted from the following analysis for the sake of statistical reliability. The analysis exhibits a few similarities and differences among the groups (Table 4, 5, and 6 in Appendix

C). The three types of learners were similar in that (1) the +structural condition had a tendency to increase both the total study time and time/access, and (2) no significant difference existed in test scores between the two conditions. One important difference seems to concern the access times in two conditions: although the +structural condition significantly decreased access times for +Structural learners, it did not for -Structural or Either learners. It seems quite natural that +Structural learners, for whom the +structural condition facilitated learning, evaluated the condition more favorably than the other two types of learners. It was also discovered that –Structural learners required the longest study time both in +structural and –structural conditions, which implies that they seemed to experience certain difficulties using the program and could not learn from it very efficiently.

Secondly, regarding their English proficiency, no significant difference was detected in GTEC scores among +Structural, Either, and –Structural students, $F(2, 62) = 1.46$, *ns*. Therefore, it is not very likely that the differences in feedback preferences were caused by those in their English ability. Lastly, as for their familiarity with computers, the questionnaire given after the immediate posttest inquired how often the participants used a personal computer per week. It was discovered that Either learners reported more experience with computers than the other two groups. While 10 out of the 12 Either students (83.3%) replied that they used a computer more than three days a week, only two out of the seven –Structural learners (28.6%) and 25 of the 46 +Structural learners (54.3%) did so. The implications of these findings will be discussed in the second part of the discussion below.

5 Discussion

5.1 Efficiency, effectiveness, and learners' evaluation of +/–structural conditions

The experiment showed that as predicted by Hypothesis 1, the +structural condition resulted in fewer access times compared with the –structural condition and that the difference reached statistical significance while it did not in Nakata (2006). The difference between the two studies can be attributed to those in the number of subjects (38 for the previous and 66 for this study). The outcome of the present experiment seems to support the hypothesis that by directing learners' attention to structural properties of target items, the +structural condition reduced misspellings in their responses, leading to fewer errors and access times as a result. However, other than the difference in access times, the results of this study corresponded to those of Nakata (2006). In other words, despite the predicted advantages of structural elaboration, once again it was confirmed that the +structural condition was neither more time-efficient nor effective than the –structural condition. This section attempts to offer some interpretations for the +structural condition's lack of time-efficiency and effectiveness.

Firstly, regarding Hypothesis 1, words studied under the +structural condition required significantly longer time than those under the –structural condition, and the results were consistent with those in Nakata (2006) ($p < .001$ for both experiments). There seem to be two reasons for this finding. The first explanation would be the time-consuming nature of structural elaboration. +Structural condition in the experiments is likely to increase the time/access because it requires an additional task of structural elaboration while the –structural does not. In formulating Hypothesis 1, I hoped that this shortcoming of the +structural condition would be offset by its ability to decrease access times. However, it emerged that the benefits of a decreased number of access times did not outweigh the time-consuming nature of structural elaboration and that the +structural condition resulted in longer total study time than the –structural.

Another explanation for the lack of efficiency of the +structural condition could be due to its inflexibility. In the previous and present experiments, the +structural condition always required learners to practice spelling of any incorrectly answered item, sometimes even unnecessarily. For example, when learners failed items not because they did not know correct spelling but because they could not access the correctly stored L2 word form due to a relatively weak word form-meaning connection, structural elaboration might have been redundant. As Thomas and Dieter (1987) and Barcroft (2002) demonstrate, structural elaboration is effective only for acquiring structural properties of L2 words and does not necessarily strengthen word form-meaning mappings. +Structural condition in this experiment might have resulted in over-learning of already learned word forms, making the learning session less time-efficient than the –structural.

As for effectiveness, Hypothesis II was also rejected because there were no significant differences in test scores between the +structural and the –structural conditions. In view of the somewhat low scores on the delayed posttest in Nakata (2006), in this study the delayed posttest was administered four days after the treatment instead of a week, hoping that this would help detect subtle differences between the two conditions. The average scores for the delayed posttest in this study were indeed higher than those in the previous study. However, as in the earlier study, there were no significant differences in test scores between the +structural and the –structural conditions. Bearing in mind that the results yielded by the two studies were not in favor of Hypothesis II, it should be maintained that the +structural condition does not lead to more effectiveness.

It seems likely that the second principle of the Low-First Method (Mizuno, 2000) may account for the lack of significant differences in test scores. The +structural and –structural conditions differed in that the former required structural elaboration while the latter did not. However, since the second principle required learners to continue studying until P_ns, weighted cumulative recall rates, for all the items reached the preset retirement criterion (Mizuno, 2000), we can speculate that the principle guaranteed a certain level of retention of the items learned under either condition and that no difference was found in learners' final attainment. In sum, the results in the present experiment confirmed that although the +structural condition seems as effective as the –structural, it is a less time-efficient way of learning.

In terms of evaluation by learners, about 70% of the participants found the +structural condition preferable, supporting Hypothesis III. The dominant reason for this inclination appeared to be their perception that typing English words helped memorization better than just looking at them, an observation confirmed by the smaller number of access times in the +structural condition than in the –structural. It is also possible that since the activity required by the +structural condition was more relevant to the learners' goals in this study, to be able to type target items, it had more face validity for the learners than the –structural condition and thus, was evaluated more favorably.

5.2 Individual differences in the effects of +/–structural conditions

The comparison of +Structural, -Structural, and Either learners suggested an interaction between the effects of the corrective feedback and the individual differences in learners. Although the +structural condition significantly decreased access times for +Structural learners, it did not for –Structural or Either learners. This leads us to wonder why the +structural condition facilitated learning only for the particular group of learners. We have already seen that due to the lack of significant difference in GTEC scores among the three groups, it would not be appropriate to ascribe the differences to those in the students' English proficiency. An interaction between the types of target items and the effects of corrective feedback is not likely either because Group A and B students happened to be equally distributed across the three groups, and the target items were counter-balanced. Then, what caused the differences in the learning outcomes?

The differences between the three groups may be attributed to those in the time/access under the –structural condition and the learners' familiarity with computers. The analysis of the learners' performance indicated a difference in the time/access under the –structural condition between +Structural and the other two types of learners: while +Structural learners spent no more than 8.01 seconds per access in the –structural condition, the other two groups spent 10.45 seconds on average, and a Mann-Whitney *U* test confirmed that the difference was significant, $U = 266.50$, $p < .05$. +Structural learners' relatively short time/access seems to imply that they closed the corrective feedback provided by the –structural condition without paying close attention to it. Therefore, they might have ended up repeating the mistakes in the subsequent trials, which was reflected in the significant difference in access times between the +structural and –structural conditions. For +Structural learners, who failed to learn effectively from corrective feedback in the –structural condition, the +structural condition facilitates learning and is desirable as they rightly evaluated it more favorably than the –structural. The time/access under the –structural condition of the four outliers identified earlier was also short (3.04, 5.13, 7.04, and 7.64 seconds per access, respectively). The records of these outliers seem to confirm the view that the short time/access is likely to lead to errors during learning and hence, result in an increase in access times.

By contrast, -Structural and Either students seemed to take enough time to confirm the corrective feedback in the –structural condition. As a result, they were more likely to give the correct answer in the following trials than +Structural learners, contributing to the non-significant differences in their access times between +structural and –structural conditions. For these two types of learners, it would be redundant to require structural elaboration as corrective feedback, and the quicker and easier –structural condition might have been sufficient. The next question would be why -Structural and Either learners disagreed on the questionnaire although their performance showed similar patterns. It may be possible that their familiarity with computers affected their responses. The questionnaire revealed that about 80% of Either learners used computers more than three times a week while less than 30% of –Structural learners did so. Since most of the –Structural learners had little experience with computers, the additional task of typing required by the +structural condition might have proven daunting or demotivating for them, contributing to their inclination towards the –structural. The comparison of the learning results also demonstrated that

-Structural group required the longest study time not only in the +structural but also in the –structural condition. This could be taken as further evidence for the speculation that due to their lack of familiarity with computers, typing with the keyboard presented challenges and turned out to be a time-consuming task for –Structural learners. On the other hand, as Either learners had more experience with and possibly more interest in computers, it is probable that they did not find the +structural condition particularly challenging and did not report aversion to the condition. It is also true that nearly half of +Structural learners reported their infrequent use of computers. However, since the +structural condition successfully decreased errors during learning for them, they probably preferred the +structural condition irrespective of their computer skills.

The results of the experiment also showed that while the –structural condition produced four outliers with a considerably large number of access times, the +structural did not. We can infer from these results that although the +structural condition reduced errors successfully for most learners, there are large variations in the extent to which the subjects can learn from the –structural condition. +Structural condition seems certainly redundant for –Structural or Either learners, but it may work in a complementary way to the –structural condition and serve learners for whom the –structural fails to facilitate learning.

In recent times, it has been widely recognized that the types of instruction interact with the individual differences in learners, and that these two factors need to be matched for effective L2 learning (Robinson, 2002). The third principle of the Low-First Method has enabled the program to adapt to individual differences in working-memory capacity (Mizuno, 2001, 2002b, 2003a), but naturally, there are more individual differences that need to be taken into account. The finding in this study seems significant because it offered a first step towards identifying such differences and demonstrated that incorporating structural elaboration into the program might make the Low-First Method better equipped to help learners with diverse learning styles. Of course, as the numbers of –Structural and Either students in this study seem a little too small to generalize, further research seems necessary in corroborating the interactions.

5.3 Towards further improvements of the corrective feedback

Although it was confirmed that the +structural condition did not lead to more effectiveness or efficiency, a discussion of whether the +structural condition is less desirable than the –structural requires further consideration for two reasons. First, the +structural condition might aid the program to adapt to individual differences in the subjects' learning styles. The condition seems especially desirable for those who do not pay close attention to the corrective feedback in the –structural condition and cannot benefit from it. The results also implied that the +structural condition might be able to help learners who would otherwise be outliers and suffer from an extraordinarily large number of access times in the –structural condition. Second, the amount of increased learning time for the +structural was not overly large (10.73 seconds per word in the former and 9.97 seconds in this study). Since the majority of the learners evaluated the +structural condition more favorably despite its lack of time-efficiency, it would be possible to maintain that the extra time needed for the +structural might be in fact negligible.

Since the +structural and –structural conditions appear to have their own advantages, if further improvement is made to the program, integrating both conditions into one type of feedback might be desirable. The easiest way to do so would be to add an "Exit" button to the corrective feedback provided by the +structural condition (Figure 3). In this new type of feedback, when learners feel the need to practice spelling, they can do so by typing the word into the box and click on the "OK" button to get it corrected. Otherwise, they can just take a look at the answer and choose to close the pop-up window by clicking on the "Exit" button. This type of integrated feedback has advantages of both +structural and the –structural conditions and might be able to satisfy learners' needs with more flexibility than either one alone.

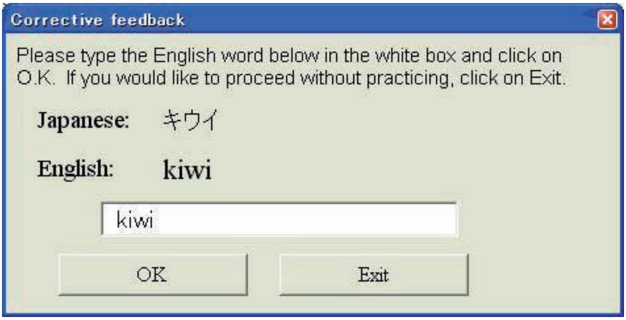

Figure 3. A new type of feedback incorporating + and – structural conditions

6 Conclusion

Although the robustness of the spacing effect has been demonstrated for more than a century, researchers in the past have not been able to take full advantage of it because of the lack of understanding of its cause. The Low-First Method is expected to contribute to the implementation of optimal spaced learning considerably because it is based on the reactivation theory, the first theory to offer a coherent explanation for the cause of the spacing effect. The findings of this study are significant because they suggest that incorporating structural elaboration into the Low-First Method may help the program decrease access times and also adapt to individual differences in learners, contributing to possible improvements of the program.

At the same time, more research is needed to address some limitations of the previous research on the Low-First Method. Firstly, the studies on the Low-First Method including the present one have addressed only limited aspects of vocabulary knowledge, namely, the written form and the form-meaning connection. It might be valuable to investigate how other aspects of word knowledge such as the spoken form or grammatical functions can be learned with a program based on the Low-First Method. The second limitation would be the relatively short duration of the experiments. All the studies on the Low-First Method have adopted a one-shot approach, where the learning session usually takes no more than 20 minutes and is completed in one day. In view of the incremental nature of lexical acquisition, further research is necessary to examine whether the Low-First Method can assist learners in managing retrieval opportunities distributed over a longer period of time. Considering that the spacing effect is too powerful to be ignored by any instructional program (Ellis, 1995), these attempts to improve the Low-First Method will offer valuable implications for L2 vocabulary teaching pedagogies.

Notes

* This paper is partly based on the author's presentation at JACET English Vocabulary Group Second Conference held in December, 2005.

1) The Low-First Method continues to test items until the P_ns, weighted cumulative recall rates, for all the items reach the preset retirement criterion (Mizuno, 2000). Consequently, the fewer errors a learner makes, the fewer access times and the less study time s/he needs to complete the learning session. A lower number of access times and less study time, therefore, are the result of a learning session with fewer errors and an indication of more efficient learning.
2) In order to minimize the effects of the subjects' prior knowledge, words that were ranked as low-frequency ones in published word lists were chosen as target words. The words were divided into Items X and Items Y so that learning difficulties measured by ranks in the word lists and number of letters would be distributed as evenly as possible.
3) The total number of the subjects is 65, not 66, because one learner did not provide an answer to the question.

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Appendices

Appendix A

Source codes for the –structural condition (in Visual Basic for Excel Version 6.0)

```
Private Sub UserForm_Activate()
    Directions.Caption = "以下の内容を確認したら、「OK」ボタンを押して下さい。"
    CueBox.Caption = Question 'Display the Japanese translation for the target item.
    ResBox.Caption = Answer 'Display the correct answer.
    OKButton.SetFocus
End Sub
Private Sub OKButton_Click()
    Unload Me
    LowFirst.RedoAction 'Exit the pop-up window when the OK button is clicked.
End Sub
```

Appendix B

Source codes for the +structural condition (in Visual Basic for Excel Version 6.0)

```
Private Sub UserForm_Activate()
    CueBox.Caption = Question 'Display the Japanese translation for the target item.
    ResBox.Caption = Answer'Display the correct answer.
    Directions.Caption = "以下の単語をボックス内にタイプして、「OK」ボタンを押して下さい。"
    AnswerBox.IMEMode = fmIMEModeOff: AnswerBox.SetFocus
    If IncorrectAns <> "" Then 'Unless the learner typed a blank response, do the following.
        YourAnswerLabel.Caption = "あなたの答え"
        YourAnswerBox.Caption = IncorrectAns 'Display the learner's incorrect response.
    End If
End Sub
Private Sub OKButton_Click()
    If AnswerBox.Text = Answer Then 'If the learner typed the correct answer, do the following.
        Unload Me: LowFirst.RedoAction 'Exit the pop-up window.
    Else 'If the response is incorrect, do the following.
        Directions.Caption = "もう一度スペリングを確かめて、入力して下さい。"
        YourAnswerBox.Caption = AnswerBox.Text 'Display the incorrect response.
        AnswerBox.Text = "": AnswerBox.SetFocus 'Clear the white box.
    End If
End Sub
```

Appendix C

Supplementary tables

Table 3. Learners' performance in +/–structural conditions

		+Structural		–Structural	
	n	M	SD	M	SD
Access times	66	25.94	7.81	29.83	16.47
Study time (sec.)	66	294.36	126.15	244.12	112.97
Time/access	66	11.35	3.51	8.66	3.61
Immediate posttesta	66	4.18	1.08	4.11	1.20
Delayed posttesta	61	1.74	1.44	1.84	1.34

Note. [a] The possible maximum score is five for each condition.

One participant was absent on the day of the delayed posttest. Four students who reported in the questionnaire that they had studied some of the target words between the study session and the delayed posttest were excluded from the analysis of the delayed posttest, making the *n* for the delayed posttest 61.

Table 4. +Structural learners' performance in +/–structural conditions

		+Structural		–Structural		Paired t tests		
	n	M	SD	M	SD	df	t	
Access times	42	24.69	6.45	26.48	7.33	41	-2.16	*
Study time (sec.)	42	265.98	104.23	213.29	88.03	41	4.19	***
Time/access	42	10.72	2.96	8.01	2.23	41	9.55	***
Immediate posttest	42	4.26	0.91	4.19	1.04	41	0.50	
Delayed posttest	40	1.98	1.51	2.15	1.42	39	-0.87	

Note. *** $p < .001$. * $p < 05$.

Table 5. Either learners' performance in +/–structural conditions

		+Structural		–Structural		Wilcoxon's	
	n	M	SD	M	SD	Z	
Access times	12	24.83	7.25	25.33	7.36	-0.28	
Study time (sec.)	12	305.08	117.52	237.83	106.96	-2.39	*
Time/access	12	12.51	4.45	10.00	6.30	-2.12	*
Immediate posttest	12	4.42	0.90	4.25	0.87	-0.65	
Delayed posttest	12	1.67	1.30	1.33	0.78	-0.86	

Note. * $p < 05$.

Table 6. -Structural learners' performance in +/–structural conditions

		+Structural		–Structural		Wilcoxon's
	n	M	SD	M	SD	Z
Access times	7	26.86	6.26	26.43	6.37	-0.11
Study time (sec.)	7	372.43	207.05	299.14	115.96	-1.02
Time/access	7	13.36	4.67	11.23	2.77	-1.52
Immediate posttest	7	4.71	0.49	4.86	0.38	-0.58
Delayed posttest	4	1.25	0.96	2.25	0.50	-1.63

Note. All values are not significant.

Appendix D

Selected excerpts from the learners' comments about the corrective feedback

+Structural learners	"I felt typing out the spelling made it easier to memorize," "With this [the +structural condition], I can memorize by using my eyes, hands, and mouth," "Typing helps me analyze word structure," "I ended up not confirming the answers very well when they just appeared on the display," "I cannot remember by just looking."
-Structural learners	"I can confirm the answers quickly," "This [the –structural condition] is simple and easy," "Typing a correct answer is tedious."
Either learners	"They [types of feedback] did not make any difference to me," "I could memorize words in either way."

Note. Learners' comments were originally written in Japanese and translated into English by the author.

About the author

Tatsuya Nakata is a graduate student at Tokyo University and an instructor at Musashino University. His research interests are L2 vocabulary acquisition and CALL. His publications have appeared in *Language and Information Sciences*, *the Rikkyo Review* and *How to Make the Best of JACET8000*. He has published four English wordbooks.