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The Impact of Neuroscience-Informed Instruction on Vocabulary Development and Retention among Iranian EFL Learners

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ABSTRACT

In many Iranian EFL classrooms, vocabulary instruction still depends largely on teacher-centered and traditional teaching practices. In these contexts, principles associated with Neuroscience-Informed Instruction (NII) are also rarely incorporated. This situation has increased interest in instructional approaches that are more consistent with how learners process and recall information. Accordingly, this study investigated the effects of NII on vocabulary development and long-term retention among Iranian EFL learners. Twenty-eight intermediate EFL learners (18–31 years old) from a private language institute in Kerman, Iran were selected through the Oxford Placement Test (OPT) and assigned to two intact classes. The experimental group received instruction based on NII principles, including spaced repetition, retrieval practice, multimodal input, emotional engagement, and brief metacognitive reflection. The control group received conventional vocabulary instruction. The intervention was carried out over twelve 90-minute sessions across six weeks. A researcher-made test measured vocabulary knowledge through a pre-test, immediate post-test, and delayed post-test. The data were analyzed using independent-samples t-tests and mixed-design repeated-measures ANOVA. Both groups improved over time; however, the experimental group achieved higher scores on both the immediate and delayed post-tests. The repeated-measures analyses also revealed a statistically significant Time × Group interaction, with the experimental group demonstrating stronger vocabulary growth and retention over time. These findings suggest that instructional practices informed by cognitive neuroscience principles may support more effective vocabulary learning and retention in EFL contexts. The findings highlight the potential value of neuroscience-informed instructional practices for vocabulary teaching in EFL contexts.

Introduction

In recent years, increasing attention has been paid to the possible role of cognitive neuroscience in classroom instruction. In language education, vocabulary learning is a major challenge, especially when learners have difficulty retaining newly learned words over time (Shoja & Karimi, 2025). Traditional techniques such as translation and rote memorization may help learners remember vocabulary for a short time, but they often fail to support durable learning. (Nation, 2013; Webb & Nation, 2017). Neuroscience-Informed Instruction (NII) draws on research related to learning and memory and applies these insights to instructional practice. Common principles associated

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with NII include retrieval practice, spaced repetition, multimodal input, emotional relevance, and reflective monitoring (Sousa, 2022; Tokuhama-Espinosa, 2021; Willis, 2020). According to Carey (2015) and Kang (2016), these strategies may strengthen memory consolidation, retrieval, and self-regulation, which are important for long-term learning. Previous studies have also shown that emotionally meaningful learning experiences are often connected with deeper engagement and stronger recall (Immordino-Yang & Damasio, 2007). In a similar way, dual coding theory (Paivio, 1990) proposes that learners are more likely to remember vocabulary when verbal information is supported through images and meaningful associations. Despite these developments, vocabulary instruction in many EFL classrooms, including those in Iran, still relies heavily on teacher-centered and conventional teaching methods. In many cases, neuroscience-informed principles are rarely integrated into everyday classroom instruction (Moghaddam et al., 2025; Sarnou, 2024; Zohrabi, 2023; Zohrabi et al., 2012). As a result, there is still a need to examine instructional approaches that align more closely with how learners process and retrieve information during language learning.

Although previous studies have reported encouraging results, several limitations can still be identified. Most previous studies focused mainly on immediate learning outcomes rather than delayed retention (Mima & Reftyawati, 2023). In addition, relatively few studies have examined structured neuroscience-informed instructional procedures in Iranian EFL settings, particularly in private language institutes in Iran. In many cases, researchers examined separate instructional techniques instead of implementing a structured instructional framework across the entire course. Therefore, additional research is needed to examine whether a structured neuroscience-informed approach can improve both vocabulary learning and long-term retention in Iranian EFL contexts. In response to these limitations, the present study sought to examine the effectiveness of a more systematically organized neuroscience-informed instructional framework. The study extends earlier research by examining a structured NII framework in an actual EFL classroom setting. Unlike many earlier studies that focused on isolated techniques or short-term outcomes, the present research included both immediate and delayed post-tests to examine vocabulary retention over time. It also focused on intermediate Iranian EFL learners in a private language institute context, which has received relatively limited attention in previous research.

In light of the gaps identified in previous research, the present study addressed the following research questions:

RQ1. Does neuroscience-informed instruction lead to significantly greater immediate vocabulary gains among Iranian EFL learners compared with conventional instruction?

RQ2. Does neuroscience-informed instruction lead to significantly better long-term vocabulary retention among Iranian EFL learners compared with conventional instruction?

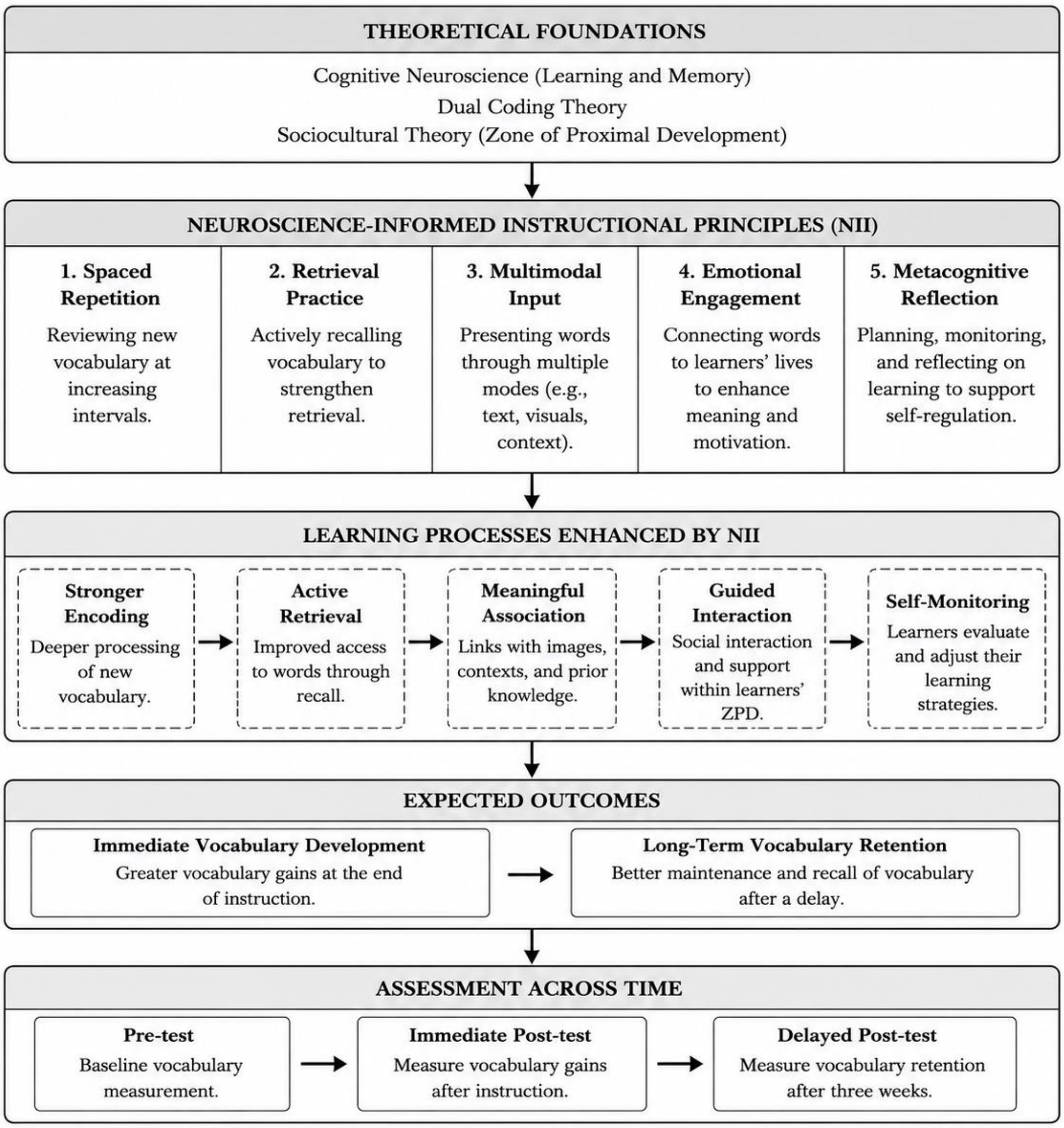
RQ3. How does vocabulary performance change over time across the experimental and control groups?

Based on previous research and the theoretical framework, it was hypothesized that learners who received NII would outperform the control group on both immediate and delayed vocabulary measures and would demonstrate stronger vocabulary retention over time.

Figure 1 presents the conceptual framework of the study. The framework shows how neuroscience-informed instructional principles, including spaced repetition, retrieval practice, multimodal input, emotional engagement, and metacognitive reflection, were expected to support vocabulary learning processes and contribute to immediate vocabulary development and long-term retention among Iranian EFL learners.

Figure 1

Conceptual Framework of the Study



Review of the Literature

Vocabulary Learning and Retention in EFL Contexts

Vocabulary knowledge is crucial for successful communication, yet many EFL learners continue to experience difficulty retaining and using newly learned words over time. (Schmitt, 2019). Unlike first-language learners, who meet new words many times in natural situations, EFL learners usually see vocabulary in word lists, separate exercises, dictionaries or tasks without real context (Nation, 2013). Many studies showed that rote memorization may help students remember words for a short time, but it usually does not help long-term retention (Barcroft, 2015). Similar findings regarding vocabulary learning strategies were reported by Dobakhti et al. (2020), who compared rote and mnemonic strategies among Iranian EFL learners. In addition, Zohrabi and Tahmasebi (2020) showed that dictogloss as a form-focused instructional activity could support vocabulary development among Iranian EFL learners. When learners do not meet words again in meaningful situations, they forget them quickly, which is similar to what Ebbinghaus's forgetting curve explained (1885/2011).

Neuroscience studies provide useful ideas about how to reduce forgetting. Research on learning and memory suggests that retrieval practice (Karpicke & Blunt, 2011; Roediger & Butler, 2011), spaced repetition (Cepeda et al., 2006), and multisensory learning (Shams & Seitz, 2008) are associated with stronger memory performance. Dual coding theory (Paivio, 2007) explained that when words are learned through both language and images, learners can better recall them. Moreover, when learning materials are emotionally meaningful, they are usually remembered more deeply (Immordino-Yang, 2015). In addition, metacognitive reflection can help learners check and control their learning strategies (Diamond, 2013; Schraw & Dennison, 1994). Integrating these principles into vocabulary instruction may therefore shift learning toward more active and durable forms of knowledge.

Neuroscience-Informed Principles Relevant to Vocabulary Learning

This study is based on ideas from cognitive neuroscience, constructivist learning theory, and neuroeducation. These perspectives view learning as a process influenced by cognition, social interaction, and instructional experience. From an instructional perspective, NII emphasizes strategies that may support encoding and retrieval processes during learning. Unlike broader brain-based learning approaches that often rely on general assumptions about learning styles or hemispheric preferences, the present study conceptualizes NII as the systematic integration of empirically supported cognitive and neuroeducational principles within classroom vocabulary instruction. Techniques such as spaced review, varied exposure, retrieval practice, and meaningful elaboration are argued to strengthen memory traces and reduce forgetting (Brown et al., 2014; Sousa, 2022; Willis, 2020). In EFL contexts, where vocabulary is easily forgotten, these strategies may be relevant. At the same time, sociocultural perspectives suggest that instructional support, interaction, and guided participation may further strengthen learners' engagement with vocabulary learning processes.

The study is also guided by Vygotsky's (1978) Sociocultural Theory (SCT) and the idea of the Zone of Proximal Development (ZPD). In this view, learning happens through social interaction, and teachers' support and scaffolding are very important. Previous educational research suggests that collaborative learning environments may support deeper engagement and repeated interaction with meaningful tasks (Doidge, 2007). These perspectives provide a conceptual rationale for examining NII as an instructional framework that may help align teaching practices more closely with how learning is theorized to occur.

Integration of Neuroscience in EFL Instruction

Educational neuroscience has grown and now offers useful ideas about how learners process information and manage their emotions. The main goal is not to replace teaching with biological explanations, but to help teachers make better instructional decisions based on research studies (Tokuhama-Espinosa, 2011; Willis, 2020). Several frameworks highlight the importance of creating learning environments that support students' affective and cognitive factors (Sousa, 2022). Strategies connected with NII particularly those emphasizing repeated retrieval, multimodal engagement, and meaningful learning experiences are often suggested as promising options (Cepeda et al., 2006; Shams & Seitz, 2008). In addition, approaches such as Universal Design for Learning (CAST, 2018) and scaffolded instruction (Meyer et al., 2014) offer structures for adapting instruction to diverse learners.

At the same time, some studies showed that many teachers do not feel fully prepared to apply neuroscience-informed strategies, and some of them still believe in ideas that are actually neuromyths (Ansari et al., 2012; Dekker et al., 2012). Therefore, professional development programs that focus on learning processes, cognitive load, and reflective teaching practices are essential (JohnBull & Hardiman, 2024). Classroom climate also matters, as chronic stress can undermine attention and memory (Immordino-Yang & Damasio, 2007; Schonert-Reichl, 2017).

Although NII appears promising theoretically, there are still many problems when teachers try to apply it in real classrooms. Some of these challenges include limited resources, exam-centered educational systems, resistance from schools, heavy workloads, limited time for training, and little access to reliable information about neuroscience (Bruer, 1997; Burkett, 2014; Dubinsky et al., 2022).

Prior Applications of Neuroscience-Informed Instruction in Language Education

Previous research in language education has generally reported positive outcomes associated with neuroscience-informed instructional practices. In different EFL contexts, these approaches have been linked to improvements in vocabulary learning, retention, reading comprehension, motivation, and learner engagement (Bayer, 2022; Kandasamy et al., 2021; Mima & Reftyawati, 2023; Salem, 2017). Many of these studies emphasized instructional principles such as retrieval practice, multimodal input, emotional engagement, and repeated exposure to vocabulary, which are believed to support stronger encoding and retention processes. These studies reported positive effects of neuroscience-informed practices on vocabulary learning in different EFL settings.

However, the existing literature also reveals several important limitations. Many studies focused primarily on immediate learning outcomes and paid relatively limited attention to delayed vocabulary retention over time. For example, although Salem (2017), Kandasamy et al. (2021), and Bayer (2022) reported improvements in vocabulary performance, the long-term stability of these gains was not examined extensively. Similarly, some studies investigated isolated NII techniques rather than implementing a systematically structured neuroscience-informed instructional framework across the full instructional process.

In addition, previous studies have varied considerably in terms of educational settings, learner age groups, and instructional procedures. While Koşar and Bedir (2018) reported sustained vocabulary development in a longitudinal design, relatively few studies have examined structured

NII protocols in adult EFL contexts or private language institutes. In the Iranian context, Haghighi (2013) and Abdolmaleki and Saeedi (2024) reported positive effects of neuroscience-informed practices, particularly when integrated with flipped learning and technology-enhanced instruction. Nevertheless, experimentally designed studies examining vocabulary retention through delayed post-tests are relatively limited.

Review studies have also highlighted broader conceptual and pedagogical concerns surrounding NII. Valdés-Villalobos and Lazzaro-Salazar (2023) and Pradeep et al. (2024) emphasized the importance of emotional, sensory, and social dimensions of learning, whereas Jolles and Jolles (2022) stressed the need for teacher education programs that help teachers distinguish research-supported principles from neuromyths. The literature points to the potential value of NII for vocabulary instruction, while also indicating the need for more systematically designed quasi-experimental EFL studies that examine both immediate learning and long-term retention.

Method

Research Design

This study employed a quasi-experimental, non-equivalent control group design with three testing times including pre-test, immediate post-test, and delayed post-test. Two intact intermediate EFL classes from a private language institute in Kerman, Iran took part in the study. They were assigned to one of two conditions: (a) an experimental group that received NII, and (b) a control group that received conventional vocabulary instruction. Because the study was conducted in an authentic classroom setting, intact classes were used and random assignment at the individual level was not feasible. However, the two classes were randomly assigned to the experimental or control condition.

Participants

The participants were 28 intermediate EFL learners (14 in the experimental group and 14 in the control group), aged between 18 and 31, studying at a private language institute in Kerman, Iran. Participants were selected through convenience sampling based on class availability and institutional access. To ensure a comparable level of English proficiency, all learners took the Oxford Placement Test (OPT) before the intervention. Only learners whose scores corresponded to the B1 level of the CEFR were included in the study. Two intact B1-level classes were then randomly assigned to either the experimental or the control group. All participants were informed about the purpose and procedures of the study and signed written informed consent forms. Table 1 presents the demographic and educational characteristics of the participants in the experimental and control groups. Ethical approval for the study was obtained from the relevant institutional review committee before data collection began.

Table 1

Demographic Characteristics of the Participants

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Variable	Experimental Group (n = 14)	Control Group (n = 14)	Total (n = 28)
Age Range	18–31	18–30	18–31
Mean Age (SD)	23.57 (3.42)	24.14 (3.76)	23.85 (3.57)
Gender			
Male	6	5	11
Female	8	9	17
Years of English Learning Experience			
Mean Years (SD)	5.21 (1.44)	5.43 (1.39)	5.32 (1.40)
Academic Status			
Undergraduate Students	9	10	19
Graduates/Employed Adults	5	4	9

Instruments and Materials

Vocabulary Test

A researcher-designed vocabulary test was developed to measure learners' receptive vocabulary knowledge related to the course material. The test had 40 items with a total score of 20. Each item was weighted at 0.5 points. It included 15 multiple-choice, 15 fill-in-the-blank, and 10 matching items. The vocabulary test mainly assessed learners' receptive form–meaning knowledge of the target lexical items taught during the intervention. Most items required learners to recognize word meanings and select appropriate lexical forms in context. All vocabulary was taken from Oxford Word Skills: Intermediate (2nd Edition) by Gairns and Redman (2020), and focused on common collocations, high-frequency phrasal verbs, and multi-word expressions taught in the selected units. The items were placed in short and real-life contexts so that learners would use the words meaningfully, not only recognize them.

To support validity, three experienced TEFL instructors with expertise in vocabulary instruction and language assessment reviewed the test for relevance and difficulty. The test was also piloted with 12 B1-level learners from the same institute, and item analysis was carried out. Items that were unclear or showed weak relations with the whole test were either revised or removed. The final version showed acceptable internal consistency reliability (Cronbach's α = .71), which was considered adequate for classroom-based research. The same test was given three times including as a pre-test at the beginning of the course, as an immediate post-test at the end of instruction, and again three weeks later as a delayed post-test.

Instructional Materials

Both groups used Oxford Word Skills Intermediate as the core instructional material. In line with the learners' proficiency level and the institute's syllabus, 24 lessons (two lessons per session) were selected, focusing on vocabulary topics relevant to everyday communication. These lessons were taught in 12 sessions over a six-week period. While the textbook content was identical for both groups, the mode of delivery differed. In the experimental group, lessons were taught through an NII-based protocol. In the control group, lessons were taught using conventional methods such as teacher explanation, translation, repetition, and textbook-based practice activities.

Neuroscience-Informed Instruction (Experimental Group)

To apply NII in a clear way, the experimental group followed a five-stage teaching routine in every session. This routine was based on principles such as spaced repetition, retrieval practice, dual coding, emotional engagement, and metacognitive reflection. Each lesson began with a short review of previously taught vocabulary through simple activities like small quizzes, and brief pair-work recall. Words from earlier lessons were revisited according to a spaced schedule. After this, students took part in guided retrieval activities that asked them to recall words actively, for example through cue-based questions and short oral prompts. The next stage focused on multimodal presentation of new vocabulary, using teacher explanation, example sentences, pictures, icons, short videos, and sometimes simple gestures. Learners were encouraged to produce their own examples or create mind maps to build stronger associations. In the fourth stage, learners connected the new vocabulary to their own lives through short speaking or writing tasks, and group discussions on personally relevant topics. Finally, each session ended with a brief reflection period, in which students thought about what helped them remember words and how they could review at home. The teacher suggested simple strategies, such as spaced self-testing and using new words in short messages. The same teacher taught both groups and received preparatory training in the NII instructional procedure before the intervention began, in order to ensure consistent implementation. To further support instructional consistency, the teacher followed the same five-stage instructional sequence throughout the intervention period.

Conventional Instruction (Control Group)

The control group received the institute's conventional vocabulary instruction procedures. Teaching mainly depended on teacher explanation of meanings, providing definition, synonyms or antonyms, translation into the learners' first language and repetition by the whole class and individual students. Learners also completed short written exercises from the textbook, such as matching and gap-fill activities with word lists. Review of previous vocabulary was limited and usually happened only before tests. Unlike the experimental group, there was no systematic use of spaced repetition, retrieval practice, emotional linking, or guided reflection. The lessons were equal in time to the experimental group (two 90-minute sessions per week for six weeks), and both groups studied the same textbook units.

Data Collection and Analysis

The intervention lasted six weeks, and both groups had two 90-minute sessions each week. In the first session (Week 1), all learners took the vocabulary pre-test under the same classroom conditions. The researcher gave and collected the test and told the students that their scores would not affect their grades. From Weeks 1 to 6, the experimental group was taught through the NII protocol, while the control group received the usual instruction used in the institute. The researcher periodically observed the classes to be sure the procedures were followed correctly. At the end of

Week 6, all learners took the same test again as the immediate post-test. Three weeks later (Week 9), the same test was given again as a delayed post-test to check longer-term retention. No additional instruction or structured review of the target vocabulary was provided during this interval.

All scores were entered into SPSS (Version 26) for statistical analysis. Descriptive statistics, including means, standard deviations, and score ranges, were first calculated for each group across the three testing occasions. Prior to the main analyses, the assumptions underlying parametric testing were examined. Normality was assessed through the Shapiro–Wilk test, while homogeneity of variance was examined using Levene's test at the pre-test stage. An independent-samples t-test was then conducted to confirm the comparability of the experimental and control groups before the intervention. To investigate changes in vocabulary performance over time and differences between groups, a mixed-design repeated-measures ANOVA was performed, with Time (pre-test, post-test, delayed post-test) treated as the within-subject factor and Group (experimental vs. control) treated as the between-subject factor. Box's M test was used to examine the equality of covariance matrices, and when the assumption of sphericity was violated, Greenhouse–Geisser corrections were applied. Partial eta-squared (η^2) values were reported to estimate effect sizes, and trend analyses were conducted to further examine patterns of vocabulary development across testing occasions. All statistical analyses were carried out at the .05 significance level.

Results

Preliminary Analyses

Table 2 presents descriptive statistics and normality test results for the vocabulary pre-test, post-test, and delayed post-test. Both groups began with comparable mean scores (Control: $M = 11.00$, $SD = 1.18$; Experimental: $M = 10.71$, $SD = 1.82$), suggesting comparable initial performance levels. Following instruction, the experimental group demonstrated a larger increase ($M = 14.50$, $SD = 2.28$) compared to the control group ($M = 12.43$, $SD = 1.16$). After three weeks, the experimental group showed a smaller decline in scores at the delayed post-test stage ($M = 13.64$, $SD = 2.41$), while the control group slightly declined ($M = 11.86$, $SD = 1.29$). Shapiro–Wilk tests indicated approximate normality for all distributions (all $p > .05$) except for the control group at post-test ($p = .039$), a minor deviation that was considered acceptable given the equal group sizes and the relative robustness of parametric analyses to modest violations of normality

Table 2

Descriptive Statistics and Tests of Normality for Vocabulary Scores

Time	Group	Mean	SD	Range	Shapiro–Wilk (Sig.)
Pre-test	Control	11.00	1.18	9–13	.090
	Experimental	10.71	1.82	8–13	.085

Post-test	Control	12.43	1.16	11–14	.039
	Experimental	14.50	2.28	11–18	.134
Delayed post-test	Control	11.86	1.29	10–14	.054
	Experimental	13.64	2.41	10–17	.076

Note. Shapiro–Wilk significance values greater than .05 indicate approximate normality.

Table 3 presents the results of the independent-samples t-test conducted on the pre-test vocabulary scores. The analysis revealed no significant difference between the experimental and control groups prior to the intervention, t(26) = 0.49, p = .625. The mean difference between the groups was small, and the confidence interval included zero (95% CI = −0.90 to 1.47), which suggests that the two groups were statistically comparable at the beginning of the study. In addition, the effect size estimates were very small (Cohen's d = 0.19; Hedges' g = 0.18), suggesting that the groups were comparable prior to the intervention.

Table 3

Independent Samples t-Test and Effect Size Estimates for Pre-Test Vocabulary Scores

Test	t(df)	p	Cohen's d	Hedges' g	Glass's δ	95% CI (Lower–Upper)
Pre-test	0.49 (26)	.625	0.19	0.18	0.16	−0.90 – 1.47

Note. Cohen's d, Hedges' g, and Glass's δ are reported as standardized effect size estimates.

Research Question 1: Does Neuroscience-Informed Instruction Lead to Significantly Greater Vocabulary Learning Among Iranian EFL Learners Compared with Conventional Instruction?

To address the first research question, an independent-samples t-test was conducted on the post-test vocabulary scores of the experimental and control groups. As shown in Table 4, the post-test results revealed a significant difference between the two groups, t(26) = 3.10, p = .005. Learners in the experimental group achieved a higher mean score (M = 14.50, SD = 2.28) than those in the control group (M = 12.43, SD = 1.16). The effect size was large (Cohen's d = 1.17) and indicated a substantial difference between the two instructional conditions.

Table 4

Independent Samples t-Test for Post-Test Vocabulary Scores

Group	M	SD	t(df)	p	Cohen's d
Control	12.43	1.16	3.10 (26)	.005	1.17

Experimental	14.50	2.28	—	—	—

Note. The t-test statistics and effect size estimates apply to the comparison between the two groups as a whole.

Research Question 2: Does Neuroscience-Informed Instruction Lead to Significantly Better Long-Term Vocabulary Retention Among Iranian EFL Learners Compared with Conventional Instruction?

To examine long-term retention, an independent-samples t-test was conducted on the delayed post-test vocabulary scores. Table 5 shows that the delayed post-test scores differed significantly between the two groups, $t(26) = 2.47$, $p = .020$. The experimental group retained more vocabulary items over time ($M = 13.64$, $SD = 2.41$) than the control group ($M = 11.86$, $SD = 1.29$). The effect size was also large (Cohen's $d = 0.93$), which suggests that the retention advantage of the experimental group was not only statistically significant but also educationally meaningful.

Table 5

Independent Samples t-Test for Delayed Post-Test Vocabulary Scores

Group	M	SD	t(df)	p	Cohen's d
Control	11.86	1.29	2.47 (26)	.020	0.93
Experimental	13.64	2.41	—	—	—

Note. The t-test statistics and effect size estimates apply to the comparison between the two groups as a whole.

Research Question 3: How Does Vocabulary Performance Change Over Time Across the Experimental and Control Groups?

To investigate changes in vocabulary performance across testing occasions, a mixed-design repeated-measures ANOVA was conducted. Table 6 presents the multivariate results of the mixed-design ANOVA. The analysis revealed a significant main effect of Time, Wilks' $\Lambda = .069$, $F(2, 25) = 169.81$, $p < .001$, partial $\eta^2 = .931$, indicating that vocabulary scores changed significantly across the three testing occasions. In addition, the Time × Group interaction was significant, Wilks' $\Lambda = .287$, $F(2, 25) = 31.03$, $p < .001$, partial $\eta^2 = .713$, which shows that the pattern of vocabulary development differed between the experimental and control groups. The large effect sizes indicated substantial differences in vocabulary performance across testing occasions and between groups.

Table 6

Multivariate Effects of Time and Time × Group Interaction on Vocabulary Scores

Effect	Wilks' Λ	F	df	Error df	p	Partial η²
Time	.069	169.81	2	25	<.001	.931
Time × Group	.287	31.03	2	25	<.001	.713

Note. Partial η² values represent effect size estimates for the multivariate analyses.

Table 7 presents the repeated-measures ANOVA and within-subjects contrasts for vocabulary scores. After applying the Greenhouse–Geisser correction, the analysis showed a significant effect of Time, $F(1.44, 37.47) = 200.35$, $p < .001$, partial $\eta^2 = .885$, indicating overall improvement in vocabulary performance across testing occasions. The Time × Group interaction was also significant, $F(1.44, 37.47) = 45.66$, $p < .001$, partial $\eta^2 = .637$, showing that the experimental group improved more substantially. A smaller reduction in scores at the delayed post-test stage was observed. Furthermore, both the linear trend, $F(1, 26) = 139.91$, $p < .001$, partial $\eta^2 = .843$, and the quadratic trend, $F(1, 26) = 345.96$, $p < .001$, partial $\eta^2 = .930$, were significant. The significant interaction trends indicated that the experimental group followed a stronger developmental pattern over time.

Table 7

Repeated Measures ANOVA and Within-Subjects Contrasts for Vocabulary Scores

Effect	F	df	p	Partial η²
Time (within-subjects)	200.35	1.44, 37.47	<.001	.885
Time × Group	45.66	1.44, 37.47	<.001	.637
Linear trend	139.91	1, 26	<.001	.843
Quadratic trend	345.96	1, 26	<.001	.930
Time × Group (Linear)	41.89	1, 26	<.001	.617
Time × Group (Quadratic)	54.76	1, 26	<.001	.678

Note. Greenhouse–Geisser corrections were applied where the assumption of sphericity was violated.

Table 8 presents the mean vocabulary scores of the two groups across the three testing occasions. Both groups showed improvement from the pre-test to the post-test stage. However, the increase was more substantial in the experimental group, whose mean score increased from 10.71 to 14.50. In contrast, the control group improved more modestly, from 11.00 to 12.43. At the delayed post-test stage, the experimental group maintained most of its gains ($M = 13.64$), whereas the control group showed a clearer decline ($M = 11.86$). Based on the observed mean scores, the experimental group retained approximately 77% of its post-test gains, whereas the control group showed a noticeably greater reduction in vocabulary performance over time. The findings indicated that learners in the experimental group achieved higher vocabulary scores across testing occasions and showed stronger retention over time than learners in the control group.

Table 8

Mean Vocabulary Scores Across Testing Times by Group

Time	Control M (SD)	Experimental M (SD)
Pre-test	11.00 (1.18)	10.71 (1.82)
Post-test	12.43 (1.16)	14.50 (2.28)
Delayed post-test	11.86 (1.29)	13.64 (2.41)

Figure 2 presents the vocabulary score patterns of the experimental and control groups across the three testing occasions. Both groups showed improvement from the pre-test to the post-test stage. However, the increase was noticeably greater in the experimental group. Although scores declined slightly at the delayed post-test stage, the experimental group maintained a higher level of performance than the control group. Therefore, the figure indicates stronger vocabulary retention over time among learners who received NII.

Figure 2

Mean Vocabulary Scores Across Testing Occasions by Group

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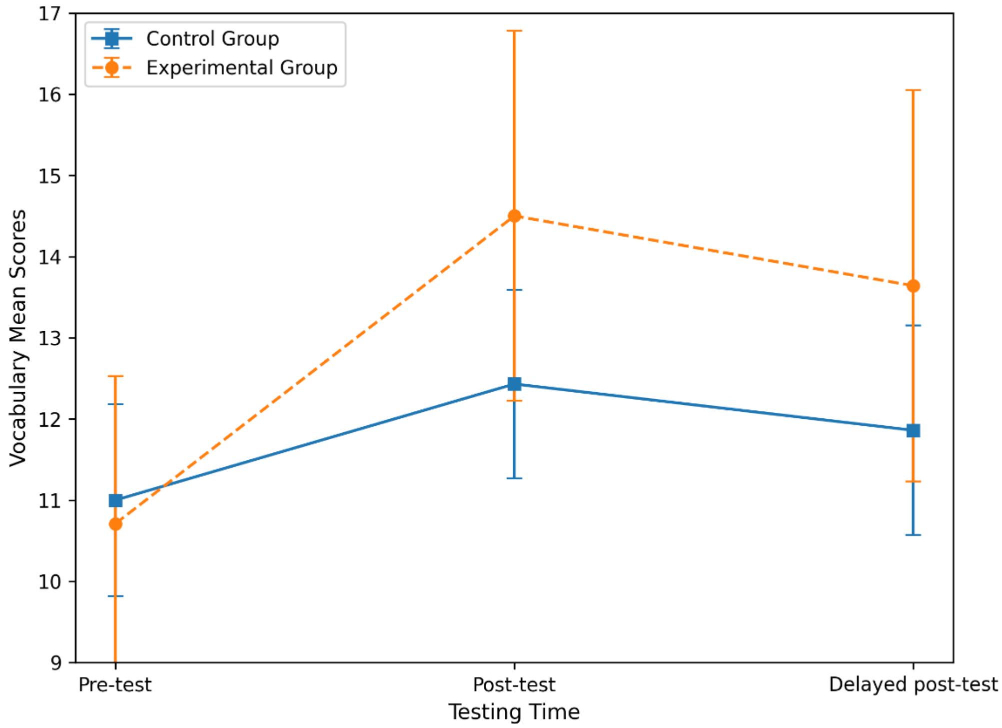

Note. Error bars represent standard deviations.

Discussion

The results showed that learners in the experimental group developed and retained vocabulary more successfully than those in the control group. Although both groups improved during the intervention period, learners in the experimental group demonstrated higher post-test performance and stronger retention at the delayed post-test stage. The improvement was visible both immediately after instruction and three weeks later, which shows that the intervention helped learners maintain vocabulary knowledge over time. The relatively large effect sizes observed throughout the analyses indicate that the differences between the two instructional conditions were not merely statistical, but also reflected meaningful differences in vocabulary performance. In addition, the present study extends previous EFL research by examining delayed vocabulary retention within a structured quasi-experimental NII framework rather than concentrating only on isolated instructional techniques or immediate post-test outcomes.

NII and Immediate Vocabulary Development

The findings related to immediate vocabulary learning are consistent with previous research which showed the importance of retrieval, emotional engagement, and multisensory processing in learning. In the present study, learners in the experimental group were exposed to instructional activities that encouraged repeated retrieval, active participation, contextualized vocabulary use, and reflective engagement with new lexical items. These practices may have facilitated deeper processing and more stable encoding of vocabulary knowledge. The findings therefore support the studies by Brown et al. (2014) and Willis (2020), who argued that learning becomes more effective

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when learners engage with information through multiple forms of processing, meaningful interaction, and active retrieval rather than passive exposure alone.

The findings are consistent with studies in vocabulary learning and second language acquisition suggesting that repeated retrieval and cognitively engaging vocabulary activities may strengthen lexical access and vocabulary recall during language use. For example, Webb and Nation (2017) emphasized that repeated encounters with vocabulary through meaningful use and retrieval-oriented activities support stronger lexical consolidation and long-term accessibility. Similarly, Barcroft (2015) suggested that deeper cognitive involvement during vocabulary processing facilitates more durable lexical encoding than passive memorization approaches. Research on retrieval-based learning by Karpicke and Blunt (2011) demonstrated that active recall activities often produce stronger retention outcomes than repeated exposure alone.

The present findings correspond with research highlighting the value of multimodal and meaningful learning experiences in vocabulary instruction. Shams and Seitz (2008) argued that multisensory learning environments may strengthen attention, memory formation, and retrieval processes. In addition, from a sociocultural perspective, Vygotsky (1978) emphasized that learning develops through meaningful interaction and instructional support. In the present study, learners were encouraged to discuss and actively use vocabulary during classroom interaction, which may have increased engagement with lexical items and contributed to stronger vocabulary development. Similarly, Nation (2013) maintained that vocabulary instruction becomes more effective when learners actively interact with lexical items in meaningful communicative contexts rather than simply memorizing isolated word lists.

NII and Long-Term Vocabulary Retention

The findings related to delayed retention are generally consistent with earlier studies reporting positive effects of NII on vocabulary learning in EFL settings (Bayer, 2022; Kandasamy et al., 2021). However, unlike many earlier investigations that focused mainly on immediate achievement, the present study incorporated a delayed post-test in order to examine whether vocabulary knowledge could be sustained over time. This aspect of the study responds to concerns raised in previous research regarding the limited attention given to long-term retention in neuroscience-informed language instruction (Mima & Reftyawati, 2023; Valdés-Villalobos & Lazzaro-Salazar, 2023).

Although the control group also demonstrated improvement during the instructional period, its performance declined more noticeably at the delayed post-test stage. In contrast, the experimental group maintained a greater proportion of its vocabulary gains over time. This pattern appears consistent with Ebbinghaus's forgetting curve and highlights some limitations associated with vocabulary instruction that relies heavily on memorization and decontextualized repetition. Some traditional approaches to vocabulary teaching may provide fewer opportunities for repeated retrieval and meaningful engagement, all of which are important for durable vocabulary retention (Barcroft, 2015; Schmitt, 2019). The instructional procedures used in the present study encouraged learners to connect vocabulary learning with meaningful activities, emotional relevance, and active reflection. These practices may have contributed to stronger retention by supporting multiple pathways for vocabulary processing and recall. In this regard, the findings are compatible with Paivio's (2007) dual coding theory as well as Karpicke and Blunt's (2011) study on retrieval practice.

Vocabulary Development Across Time

The longitudinal findings of the study also support constructivist perspectives on learning, particularly Vygotsky's (1978) view that learning develops more effectively when learners receive appropriate support and participate actively in socially meaningful learning experiences. When such principles are combined with retrieval-based learning and repeated engagement with vocabulary items, vocabulary development may become more stable across time. The repeated-measures analyses showed that the experimental group followed a stronger developmental trajectory and demonstrated a smaller decline in delayed post-test performance. This pattern supports the role of repeated retrieval, meaningful processing, and reflective learning activities in sustaining vocabulary knowledge over extended periods. The metacognitive components of the intervention may also have helped learners become more aware of their own learning processes and encouraged more active control over vocabulary review and recall.

More broadly, the findings respond to recent calls in the literature (e.g., Tokuhama-Espinosa, 2021; Willis, 2020) for instructional approaches that align more closely with principles associated with durable learning and retrieval-based instruction. At the same time, these interpretations should be understood as pedagogical explanations based on established learning theories rather than direct claims about learners' neural activity or brain functioning.

From a pedagogical perspective, the findings suggest that neuroscience-informed instructional practices may complement more traditional forms of vocabulary teaching in EFL classrooms. Simple strategies such as spaced review, retrieval-based tasks, multimodal presentation, and reflective learning activities may support teachers to create learning environments that encourage stronger vocabulary development without requiring major curricular changes or expensive instructional resources.

Limitations of the Study

Despite the positive findings, several limitations should be considered when interpreting the results of the present study. The relatively small sample size may limit the statistical generalizability of the findings. This study was conducted in only one private language institute in Kerman, Iran, which may reduce the transferability of the results to other educational settings such as public schools, colleges, universities, or online learning environments. The intervention lasted only six weeks, and the delayed post-test was administered three weeks after instruction. Although the findings suggested improved retention over time, longer intervention periods and extended follow-up measures would provide a clearer understanding of the long-term effects of NII on vocabulary development and retention. In addition, the study focused only on intermediate-level learners, and learners at different proficiency levels may respond differently to neuroscience-informed instructional practices. Because intact classes were used in a quasi-experimental design, complete randomization at the individual level was not possible. This issue may have influenced group comparability despite the use of pre-test homogeneity checks. Furthermore, although the same teacher instructed both groups in order to maintain instructional consistency, possible teacher-related influences cannot be fully excluded. Despite these limitations, the findings provide preliminary support for the pedagogical value of neuroscience-informed instructional practices in EFL vocabulary education.

Conclusion

This study examined the effect of NII on Iranian intermediate EFL learners' vocabulary development and long-term retention in a quasi-experimental context. The findings suggested meaningful differences for learners who received NII. Compared with traditional teaching, NII, which incorporated several neuroscience-informed instructional principles, helped learners both develop vocabulary knowledge and retain it more effectively over time. The findings also showed that the experimental group followed a stronger developmental pattern across testing occasions and maintained its gains more successfully than the control group. These results suggest that vocabulary knowledge may be retained more effectively when classroom instruction incorporates repeated retrieval, cognitively engaging activities, and opportunities for spaced review. From a pedagogical perspective, the findings indicate that integrating neuroscience-informed principles into vocabulary instruction may support more stable and sustained learning outcomes over time.

Methodologically, the study contributes to the literature on neuroscience-informed language instruction in several ways. It implemented a structured NII protocol within a longitudinal quasi-experimental design and examined both immediate vocabulary learning and delayed retention. In this way, the study moves beyond generalized discussions of brain-based teaching by examining how systematically organized neuroscience-informed principles may function in an actual EFL vocabulary classroom. Beyond its methodological contribution, the study contributes to the intersection between educational neuroscience and language pedagogy. The findings support the view that vocabulary learning may benefit from instructional approaches that combine retrieval-based learning, meaningful engagement, and socially supported interaction within EFL classrooms The findings demonstrate how theoretically grounded instructional principles may lead to practical classroom procedures in EFL settings. Traditional methods such as translation and rote memorization may be complemented by instructional approaches that encourage repeated retrieval and meaningful vocabulary use. When vocabulary is introduced through meaningful, emotionally engaging, and cognitively rich activities, learners are more likely to remember new words and use them appropriately in real-life situations. Therefore, teacher education programs may benefit from including basic training in neuroscience-informed instructional strategies so that teachers can apply techniques that match how learners process information. These strategies do not require expensive materials or complicated planning. Even small changes, such as using pictures, repeating key ideas, ongoing evaluations or linking new words to students' personal experiences, may support vocabulary learning and retention. At the curriculum level, policymakers and material developers may benefit from promoting vocabulary work that values depth rather than quantity. Instead of focusing mainly on long word lists or repeated test drills, instruction should provide spaced practice and frequent opportunities for retrieval in different contexts. Assessment practices may also benefit from measuring what learners can still remember and apply after some time has passed, rather than only testing immediate recall.

Future studies are encouraged to continue this line of research. Studies using larger and more diverse samples across different regions, institutions, age groups, and educational contexts would help strengthen the generalizability of the findings. It would be useful to explore whether learners at different proficiency levels respond differently to NII, and to compare the relative effectiveness of specific neuroscience-informed strategies such as dual coding, retrieval practice, spaced repetition, and reflective learning activities. Extending the follow-up period could show how long vocabulary retention can be sustained over extended periods of time. In addition, qualitative methods such as interviews and classroom observations could provide deeper insight into how students experience and perceive NII. Overall, the findings suggest that neuroscience-informed instructional practices may offer a promising and pedagogically meaningful direction for supporting vocabulary learning and retention in EFL education.

Conflict of interests

The authors declare that they have no conflict of interest.

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