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NEUROSCIENCE-INFORMED INSTRUCTION AND ITS IMPACT ON COGNITIVE ENGAGEMENT AND EXECUTIVE FUNCTION AMONG EFL LEARNERS

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Abstract
In many EFL classrooms, teachers still rely on traditional, teacher-centred practices that may not fully support how the brain learns. Neuroscience-informed instruction (NII) has been proposed as an approach that may help improve learners' attention and self-control during learning. This study examined the extent to which NII may influence Iranian EFL learners' cognitive engagement and executive function. Using a quasi-experimental design, twenty-eight intermediate learners in two intact classes at a private language institute in Kerman, Iran, were assigned to an experimental group receiving NII and a control group taught through conventional practices. NII strategies included spaced repetition, emotionally meaningful tasks, multimodal activities, and guided reflection. The control group followed textbook-centred instruction. Cognitive engagement and executive function were measured using the Cognitive Engagement Subscale of the Classroom Engagement Inventory and the Executive Function Index. Results indicated greater improvement in both variables for the experimental group. Although effect sizes were substantial, they should be interpreted cautiously given the small sample and intact-class design. The findings suggest that carefully structured NII may support learners' mental involvement and self-regulation in EFL contexts. Implications and recommendations are discussed.

Keywords: brain-based learning, cognitive engagement, EFL pedagogy, executive function, neuroscience-informed instruction

Introduction
The growth of investigation at the intersection of neuroscience and education has generated interest in how insights about the brain might impact classroom practice. In English as a Foreign Language (EFL) education, this discussion is relevant, since many instructional contexts continue to rely heavily on conventional practices such as teacher-cantered explanations and test-driven routines. These approaches may not fully support learners' mental involvement and higher-order thinking (Moghaddam et al., 2025; Zohrabi et al., 2012). In response to these

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limitations, one emerging approach that has been proposed is Neuroscience-informed instruction (NII).

NII seeks to employ principles from cognitive and affective neuroscience, such as attention, memory, cognitive load, and neuroplasticity, into pedagogical decision-making (Rogers & Thomas, 2022; Tokuhama-Espinosa, 2021). Rather than promoting isolated brain tips, NII emphasizes structured learning environments that can lead to retrieval practice, emotional relevance, reflective thinking, and multimodal engagement (Sousa, 2022; Willis, 2020). These elements, if appropriately integrated, may promote both linguistic development and broader cognitive functioning. At the same time, some researchers caution against overly optimistic claims about neuroscience in education. Concerns include the persistence of neuromyths, the oversimplification of complex brain processes, and limited evidence on how neuroscientific concepts can be incorporated into authentic classroom practices (Dekker et al., 2012; Jolles & Jolles, 2022). Therefore, NII must be examined empirically and context-sensitively rather than assumed to be universally beneficial.

In recent years, several studies (e.g., Alkhassawneh & Al Sharif, 2025; Muhammad & Saleh, 2024; Pradeep et al., 2024; Walsh et al., 2024) have attempted to explore the application of neuroscience-informed or brain-based approaches in educational contexts. Some of these studies have reported positive associations between such approaches and learners' engagement, attention, and cognitive development. However, many of these investigations have been conducted in general education settings rather than in EFL contexts, and their findings may not be directly transferable to language classrooms.

In Iranian EFL contexts, learners frequently experience classroom environments characterized by passive participation and limited reflective engagement (Mousavi & Ketabi, 2021). Executive functions, such as working memory and cognitive flexibility, are not often addressed explicitly in language instruction. However, research has shown that these functions play an important role in handling demanding language tasks and in regulating attention (Diamond, 2013; Obermeyer et al., 2020; Shokrkon & Nicoladis, 2022). As a result, when these skills are not sufficiently supported, learners may experience difficulty maintaining sustained focus and effectively monitoring their own performance during language activities. Neuroscience-informed approaches may address these challenges. Strategies such as scaffolded collaboration, spaced learning, emotional anchoring, and guided reflection align with mechanisms linked to executive control and deeper processing (Immordino-Yang & Damasio, 2007; Willis, 2020). However, empirical investigation on how these strategies operate in EFL classrooms in Iran seem to be limited.

Moreover, limited empirical attention has been given to how NII functions within EFL classrooms, especially in relation to both cognitive engagement and executive function. Existing studies have often focused on single variables or have not examined how these constructs may develop simultaneously within an instructional context. In addition, the mechanisms through which neuroscience-informed strategies may influence learners' cognitive engagement and executive function in classroom settings have not been sufficiently explained. Many studies also rely on short-term or limited measurements, which may not fully capture the dynamic interaction between these constructs during sustained instructional

interventions. In contrast to previous research, the present study does not examine cognitive or affective outcomes in isolation. Instead, it adopts a more integrated perspective by considering both cognitive engagement and executive function within the same instructional framework.

Accordingly, the present study attempted to investigate the role of NII in supporting Iranian EFL learners' cognitive engagement and executive function through a quasi-experimental design. Rather than assuming direct causal relationships, this study explored whether, and to what extent, structured NII may be associated with changes in learners' cognitive involvement and self-regulatory processes within an authentic instructional context. The findings of this study are expected to contribute to a more context-sensitive understanding of how neuroscience-informed practices may function in EFL classrooms. This research addressed the following two questions:

1. To what extent does neuroscience-informed instruction influence EFL learners' cognitive engagement?
2. To what extent does neuroscience-informed instruction influence EFL learners' executive function?

Literature review

Neuroscience-informed instruction

NII employs cognitive and affective neuroscience to inform how classroom contexts are designed and how learning activities are structured. Rather than advocating simplistic brain-based strategies, NII emphasizes theoretically grounded principles such as attention, memory, neuroplasticity, cognitive load, and emotional processing. Moreover, it considers how these mechanisms function in real learning contexts (Rogers & Thomas, 2022; Tokuhama-Espinosa, 2021). The view that instructional practices should align with how the brain encodes, consolidates, and retrieves information is central in NII. Moreover, NII emphasizes that affective and cognitive processes are deeply related in learning. In various disciplines, a range of strategies were characterized as consistent with NII, including spaced repetition, retrieval practice, multimodal learning, emotionally meaningful content, reflective thinking, and structured opportunities for collaboration (Alkhassawneh & Sharif, 2025; Carey, 2015; Cornuault, 2025; Willis, 2020). These strategies have been associated with improved attention regulation and memory consolidation processes in empirical studies on learning and cognition (Bouchey et al., 2021; Collins & Wamsley, 2020; Mocanu, 2026), and may therefore contribute to more durable learning outcomes. In EFL contexts, NII is increasingly viewed as a shift away from passive memorization and heavy reliance on textbooks toward environments which encourage active processing and strategic use of language. While these perspectives give a helpful conceptual base, it is still not completely clear how these ideas can be applied in real EFL classrooms to produce measurable cognitive outcomes.

Although there is a lot of enthusiasm in NII, researchers caution that it is vulnerable to overgeneralization and neuromyths if neuroscientific findings are misinterpreted or detached from pedagogical theory (Dekker et al., 2012; Jolles & Jolles, 2022). Therefore, empirical studies are recommended to avoid assuming that brain-based automatically implies effective, and instead explore how theoretically justified practices can function in authentic classrooms with specific learners and sociocultural contexts. However, the available studies still show positive results.

Studies reported that classrooms based on NII can improve vocabulary retention, motivation, comprehension, and students' persistence in learning (Bayer, 2022; Kandasamy et al., 2021; Salem, 2017). Long-term programs also show that the positive effects can continue. When learners receive scaffolded repetition and take part in activities that are emotionally engaging over time, their vocabulary retention seems to remain strong (Koşar & Bedir, 2018; Sahin &Yavuz, 2025). More recent studies that use flipped learning and technology-based instruction have reported better vocabulary learning and reading comprehension, especially when neuroscience-informed strategies are used in a systematic way (Abdolmaleki & Saeedi, 2024; Mima & Reftyawati, 2023). However, these findings should be interpreted with some caution, as many of these studies focus on general learning outcomes and do not always examine the underlying cognitive processes that may explain these improvements.

Systematic reviews have emphasized that the success of NII depends on factors such as teacher knowledge and deliberate integration rather than isolated technique adoption (Pradeep et al., 2024; Valdés-Villalobos & Lazzaro-Salazar, 2023). This reinforces the need for research explicitly linking NII practices to measurable processes such as cognitive regulation and engagement, rather than focusing only on surface learning outcomes.

Executive function and language learning

Executive function (EF) refers to a cluster of higher-order cognitive processes, including working memory, inhibitory control, planning, and cognitive flexibility, that help individuals regulate behaviours and persist in goal-directed activities (Diamond, 2013; Zelazo, 2015). These skills can support students' academic success and are very important in second language learning. In this context, learners need to control their understanding and change their strategies when the tasks are different (Frolli et al., 2022; Obermeyer et al., 2020; Shokrkon & Nicoladis, 2022).

Educational research increasingly views EF not as fixed but as responsive to developed instructional environments. Classroom practices involving problem solving, decision-making, collaborative reflection, and emotionally engaging experiences have been shown to stimulate neural pathways associated with executive regulation (Diamond & Lee, 2011; Yao et al., 2024). However, many of the current studies are still correlational. They mainly investigate the relationship between bilingualism and executive functions and hardly ever focus on classroom interventions that are intentionally designed to develop EF in normal teaching situations. (Musskopf & Barbosa, 2022; Treffers-Daller et al., 2020). As a result, there is still a limited understanding of how EF can be developed through structured instructional interventions in EFL classrooms. This gap is evident in Iranian settings where instruction is frequently teacher-centred and examination-driven, providing limited opportunities for scaffolded decision-making and reflective regulation.

Cognitive engagement in EFL learners

Cognitive engagement refers to learners' psychological investment in making sense of content. This concept is characterized by sustained mental effort, strategic thinking and self-regulation (Halverson & Graham, 2019). Within widely recognized engagement frameworks, cognitive engagement is one of four major

dimensions, alongside behavioural, emotional and agentic engagement, and reflects the depth of processing learners apply to complex tasks (Xu et al., 2023).

Cognitive engagement in EFL contexts can be noticed when learners try to guess meanings, discuss and clarify ideas with their classmates, use metacognitive strategies and carefully revise their language production (Philp & Duchesne, 2016). Learners highly engaged usually continue working on difficult speaking and writing tasks and consciously plan and assess their learning strategies (Sun & Zhang, 2024). Some studies have shown that cognitive engagement is strongly related to academic development in both face-to-face and online learning. For example, studies using structural equation modelling in online EFL classes found that students who invested more mental effort reached higher proficiency levels (Alshammari & Alrashidi, 2024). Still, how instructional design can influence this engagement, particularly when using neuroscience-informed approaches, is not yet clearly examined.

Moreover, neuroscience helps explain how engagement functions. Because working memory is limited, learners can only deal with a few pieces of information at the same time. Therefore, teachers need to break material into smaller chunks to avoid cognitive overload and to support deeper processing (Oakley & Sejnowski, 2021). Studies (e.g., Jamil & Belkacem, 2024) have shown that, during collaborative learning, students' brain activity can become more synchronized, and this synchrony is related to better concentration and retention. In addition, when learning has emotional value for students, the amygdala and hippocampus work together more strongly (Li et al., 2020). This may help memory, especially when students are already making cognitive effort (Immordino-Yang, 2015).

Several classroom strategies have been shown to support cognitive engagement. These include small task cycles that combine group work with reflection (Järvelä et al., 2016), multimodal chunking that matches the limits of working memory (Mansouri et al., 2024), activities that include movement to refresh attention (Basso et al., 2021), repeated feedback processes that help students monitor their learning (Cheng & Zhang, 2024), and emotional prompts that link language learning to students' personal lives (Boekaerts, 2010). These findings indicate that cognitive engagement is a combined neurological, cognitive and emotional construct that may help learners internalize language and transfer it to new situations. Taken together, these findings suggest that cognitive engagement is not only a behavioural or psychological construct, but also a process closely linked to cognitive regulation. However, its relationship with executive function within structured instructional approaches remains insufficiently examined.

Theoretical framework

This study is built on an integrated theoretical framework that combines insights from educational neuroscience, constructivist theory and self-regulation research. Together, these perspectives help explain how NII can enhance learners' cognitive engagement and support the growth of executive functions.

From the perspective of educational neuroscience, effective teaching should match the way the brain takes in, and organizes information. It highlights the value of techniques such as spaced repetition, multiple forms of input, emotional relevance, and reflective activities (Tokuhama-Espinosa, 2015). These elements

help students consolidate new knowledge, reduce unnecessary cognitive load, and build stronger neural connections that support long-term memory (Sousa, 2022).

Constructivist theory adds to this perspective since it argues that learning is actively built through scaffolding and participation in the Zone of Proximal Development (ZPD) (Vygotsky, 1978). Insights from neuroscience on neuroplasticity showed that repeated practice in social contexts can gradually reshape neural pathways and strengthen learning over time (Gkintoni, Antonopoulou, et al., 2025; Gkintoni, Vassilopoulos, & Nikolaou, 2025). In this sense, NII applies constructivist ideas through planned peer collaboration and tasks that become gradually more challenging.

Self-regulated learning (SRL) explains how students take control of their own learning. It highlights three main processes including planning, monitoring, and evaluating what they do (Callan et al., 2021). Neuroscience studies have shown that these processes use parts of the brain that control attention and decision-making (Damasio, 2005; Immordino-Yang, 2015). When learning is emotionally meaningful, students become more engaged, and this may also help develop executive functions (Obermeyer et al., 2020; Shokrkon & Nicoladis, 2022; Zelazo, 2015).

Bringing these perspectives together, NII is conceptualized in this study as a teaching approach that (1) organizes learning so it fits how the brain works, (2) encourages emotional involvement in learning, and (3) provides step-by-step support for reflection and self-regulation. In theory, these elements first increase students' cognitive engagement. Over time, they may also help develop executive functions, especially in EFL tasks that need long attention and careful monitoring and thinking. Studying this process in real Iranian EFL classrooms helps fill important gaps in the literature and builds stronger connections between neuroscience and applied linguistics. Despite several studies in these areas, few investigations have attempted to integrate these perspectives within a single empirical framework in EFL contexts.

The literature generally suggests that NII can support language learning, and that cognitive engagement and executive function play important roles in how students benefit from instruction. However, only a small number of studies explored how planned NII programs affect both of these constructs at the same time in regular EFL classrooms. Evidence from Iranian context is also still limited. Therefore, the present study attempts to examine whether NII may be associated with developments in intermediate EFL learners' cognitive engagement and executive function.

Methodology

Design

This study employed a quasi-experimental pretest-post-test design with two intact classes. One class served as the experimental group and received NII, while the other class served as the control group and received conventional teaching. This design was considered appropriate for examining instructional effects in real classroom contexts, where full experimental control is usually not possible. At the same time, the use of pretest-post-test measures allowed a more controlled comparison of changes between the groups. Although this design reduced randomization, it made it possible to study the effects of instruction in real

classroom conditions and increased ecological validity. To reduce bias, both groups were instructed by the same teacher, used the same textbook, studied the same lessons, followed the same timetable, and took the same tests.

Participants

The participants were 28 Iranian EFL learners (14 in each group). Although the sample size (N = 28) may appear relatively small, this is consistent with classroom-based quasi-experimental studies where intact groups are commonly used due to practical constraints (Creswell & Creswell, 2017). In such contexts, access to participants is often limited by institutional conditions. Moreover, repeated-measures designs can increase statistical power and sensitivity, even when sample sizes are relatively small (Field, 2024). Nevertheless, the findings should be interpreted with caution and should not be generalized beyond similar contexts. The participants were enrolled in an intermediate course at a private language institute in Kerman, Iran. Their ages ranged from 18 to 31. This age range was selected because executive function is generally considered to reach relative stability in young adulthood which allows for more consistent measurement across participants (Diamond, 2013; Ferguson et al., 2021).

To make sure that both groups were at a similar level, all participants took the Oxford Placement Test (OPT). The scores were interpreted based on available guidelines that link OPT results to CEFR levels (Oxford University Press, n.d.; Radboud in'to Languages, n.d.). In this study, learners who scored between 40 and 60, which corresponds to the B1 (intermediate) level, were selected. At this level, learners are generally able to understand main ideas and produce simple connected language in familiar situations (Council of Europe, 2001). OPT is widely used as a placement tool in language education, and its connection to CEFR levels has been applied in many contexts. This helps support the validity and consistency of classifying learners' proficiency in the present study.

After that, the two intact classes were assigned as the experimental and control groups. Ethical approval was obtained from the Ethics Committee of Kerman Islamic Azad University, and informed consent was collected in Persian before data collection. Students were informed that participation was voluntary and their responses would remain confidential. All data were anonymized by assigning numerical codes to participants, and no identifying information was stored alongside the responses. Table 1 presents a summary of participants' demographic characteristics, including age, gender distribution, and English learning background.

Table 1. Demographic characteristics of the participants

Variable	Experimental Group (n = 14)	Control Group (n = 14)	Total (N = 28)
Age Range	18–30	19–31	18–31
Mean Age (SD)	24.3 (3.6)	25.1 (3.9)	24.7 (3.7)
Gender (Male)	6	8	14
Gender (Female)	8	6	14
Proficiency Level	B1 (Intermediate)	B1 (Intermediate)	B1 (Intermediate)
Institution	Private Institute (Kerman, Iran)	Private Institute (Kerman, Iran)	Private Institute (Kerman, Iran)

Instruments and materials

Two instruments and one instructional material were utilized in this study:

Classroom Engagement Inventory-Cognitive Engagement Subscale (CEI)

Learners' cognitive engagement was assessed using the Cognitive Engagement Subscale of the Classroom Engagement Inventory (Wang et al., 2014). This subscale includes eight items that are answered on a seven-point Likert scale. The items measure students' mental effort, use of strategies, elaboration, and reflection. The internal consistency of the subscales, as estimated using McDonald's omega, ranged from .82 to .90. (Wang et al., 2014), and it has been widely used in both school and university contexts. In the present study, the scale was given to students at the pretest and again at the post-test.

Although the CEI has been widely validated in different educational contexts, its suitability for Iranian EFL learners was carefully examined in the present study. First, the instrument was reviewed by two experts in applied linguistics to check its linguistic clarity and cultural appropriateness. In addition, a pilot study was conducted with a small group of learners to ensure that all items were clearly understood. Based on the feedback, minor modifications were made to some of the item wording. The internal consistency of the instrument was found to be acceptable in this study (Cronbach's $\alpha = .83$), indicating that it was reliable for use in this context.

Executive Function Index (EFI)

EF was measured using Spinella's (2005) Executive Function Index (EFI). This questionnaire has 27 items and students rate themselves on a five-point Likert scale. It measures five areas including planning, inhibitory control, organization, empathy, and motivational drive. EFI has shown acceptable internal consistency ($\alpha = .82$) and is appropriate for studies with adolescents and adults. In this study, the EFI was used at both the pretest and the post-test.

Although both instruments relied on self-report, they were chosen because they assess learners' perceived engagement and executive function in ways that match the cognitive and emotional processes emphasized in NII. The limitations of using self-report tools are discussed later in the conclusion section.

To ensure the contextual appropriateness of the EFI, the questionnaire was reviewed and piloted with a group of learners from a similar background. Based on this process, the wording of several items was slightly simplified to improve understanding. Previous research reported satisfactory reliability for the EFI, with an overall alpha coefficient of .82 and subscale reliabilities ranging from .55 to .74 (Spinella, 2005). The internal consistency of the EFI in the present study was acceptable (Cronbach's $\alpha = .82$), suggesting that the instrument functioned reliably with this sample.

Instructional material

Both groups used *Oxford Word Skills: Intermediate (2nd Edition)* as their main textbook. The book presents vocabulary through topics, communicative tasks, and structured exercises. The important difference between the two groups was not the content, but the way the vocabulary was taught. The control group received traditional textbook-based instruction. The lessons mainly focused on teacher

explanation, modelling, translation, and repeated practice. The experimental group worked with the same vocabulary, but the instruction followed neuroscience-informed principles. Activities included spaced repetition, retrieval practice, emotionally meaningful tasks, multimodal input (such as pictures, gestures, and discussion), collaborative work, and guided reflection with self-monitoring.

In practice, each lesson followed a repeated cycle. First, students activated prior knowledge through short personal prompts. Then, the new vocabulary was presented and explored using multimodal techniques. Next, students practiced in small collaborative tasks, discussed their learning reflectively, and finally reviewed previously taught words through spaced repetition. This lesson structure was intended to align with principles of cognitive load management and neuroplastic learning. In this way, the key difference between the two groups was not the instructional content, but the cognitive and pedagogical structure through which the content was delivered.

Data collection procedures

The intervention lasted six weeks and included twelve sessions of 90 minutes each, taught twice a week. Before instruction began, students completed the CEI and EFI as baseline measures, after taking OPT. They also received a short orientation that explained the study procedures and confidentiality. During the intervention, both groups studied the same units from Oxford Word Skills: Intermediate (2nd Edition), but their instructional experiences were different. The control group received traditional textbook-centred instruction, with emphasis on explanation and written practice. The experimental group, however, took part in NII. This included spaced repetition, retrieval practice, multimodal tasks, collaborative activities, emotionally meaningful prompts, and guided reflection.

To minimize teacher-related bias, both groups were taught by the same instructor, who had experience with both traditional and NII-based lessons. A lesson plan was prepared in advance for each condition to maintain consistency across sessions. This procedure helped reduce variation related to teaching style and strengthened the internal validity of the study. To ensure treatment fidelity, four sessions (two from each group) were observed using a structured checklist. The checklist included criteria such as adherence to the lesson sequence, use of key instructional components (e.g., retrieval practice, collaboration, and reflection), time management, and patterns of student engagement. This process helped confirm that the intervention was implemented in a consistent manner. At the end of the six weeks, CEI and EFI were given again to both groups.

Data analysis procedures

Before analysis, the data were screened for missing values and outliers. Assumptions for statistical testing were examined prior to analysis. Shapiro–Wilk tests indicated that the data were normally distributed for both groups across time points ($p > .05$). Levene's tests confirmed homogeneity of variances ($p > .05$), and Box's M test was not significant ($p > .05$), supporting the equality of covariance matrices. Since the assumptions were met, mixed-design ANOVAs were run separately for cognitive engagement and executive function. Mixed-design ANOVA was selected because it allows for the examination of both within-group changes over time and between-group differences simultaneously. Time (pretest vs.

post-test) was the within-subjects factor, and group (experimental vs. control) was the between-subjects factor. Effect sizes were reported using partial eta squared (η^2), and were interpreted carefully because of the small sample and quasi-experimental design.

Several steps were taken to improve validity and reliability. These included using well-validated instruments, establishing similar proficiency levels at baseline, keeping the curriculum the same across groups, teaching the classes by the same instructor and monitoring instructional fidelity. However, the study still has some limitations, such as the use of intact classes, reliance on self-report questionnaires, and the relatively small sample. These points are discussed later in more detail in the conclusion section. Generally, these procedures aimed to combine ecological validity with methodological care, while allowing cautious interpretation of the findings.

Findings and Discussion

Findings

Descriptive statistics, assumption testing, and mixed-design ANOVA outcomes are presented for each construct. Effect sizes are reported using partial eta squared (η^2).

The influence of neuroscience-informed instruction on EFL learners' cognitive engagement

Both groups began the study with comparable levels of cognitive engagement. Table 2 shows that the control group increased slightly from pretest to post-test, whereas the experimental group demonstrated a more considerable improvement following the intervention.

Table 2. Descriptive statistics for cognitive engagement by group and time point

Group	Time	M	SD	Min	Max	Skewness	Kurtosis
Control	Pre-test	3.98	0.32	3	4	0.19	-1.14
Experimental	Pre-test	3.90	0.39	3	4	-0.35	-0.62
Control	Post-test	4.19	0.34	4	5	0.41	0.16
Experimental	Post-test	5.32	0.40	5	6	-0.45	-1.09

Before running the analyses, all statistical assumptions were checked (see Table 3). The Shapiro–Wilk tests showed no serious violations of normality. Levene's tests confirmed that the variances were equal across groups at both testing points, and Box's M test was not significant, indicating equality of covariance matrices. Because the study included only two time points, the assumption of sphericity was automatically satisfied. Therefore, these results justified the use of mixed-design ANOVA.

Table 3. Summary of assumption tests for cognitive engagement

Test	Pre-test *p*	Post-test *p*	Interpretation
Shapiro–Wilk (Control)	.430	.736	Normal
Shapiro–Wilk (Experimental)	.852	.244	Normal
Levene's Test	.516	.340	Equal variances
Box's M Test	—	.211	Equal covariances
Sphericity	—	Met	2 time points

Results of the mixed-design ANOVA are presented in Table 4. There was a significant main effect of Time, showing that cognitive engagement increased over the course of the study, $F(1, 26) = 419.08$, $p < .001$, $\eta^2 = .94$. More importantly, the Time × Group interaction was also significant, $F(1, 26) = 233.94$, $p < .001$, $\eta^2 = .90$, which indicates that the amount of change was different for the two groups. As shown in the estimated marginal means (Table 5), the experimental group increased from M = 3.90 to M = 5.32, while the control group showed only a small increase from M = 3.98 to M = 4.19. The 95% confidence intervals at post-test did not overlap which suggests a difference between the groups.

Although the effect sizes were large, they should be interpreted with caution. Due to the relatively small sample size and the quasi-experimental design, these values may be somewhat overestimated. Therefore, the magnitude of the effects should be considered as indicative rather than conclusive. These results indicate that students receiving NII reported higher levels of mental effort, strategic thinking, and reflective engagement than those taught through conventional instruction.

Table 4. Mixed ANOVA results for cognitive engagement

Source	df	F	Sig.	Partial η^2
Time	1, 26	419.08	.000	.942
Time × Group	1, 26	233.94	.000	.900
Between-Subjects (Group)	1, 26	16.03	.000	.381

Table 5. Estimated marginal means and interaction effects for cognitive engagement

Group	Time	Mean	SE	95% CI (Lower–Upper)
Control	Pre	3.98	.10	3.79–4.17
Control	Post	4.19	.10	3.99–4.39
Experimental	Pre	3.90	.09	3.71–4.09
Experimental	Post	5.32	.10	5.12–5.52

Figure 1 illustrates change in cognitive engagement across time for both groups. Although both groups improved from pretest to post-test, the experimental group showed a noticeably steeper increase compared with the control group.

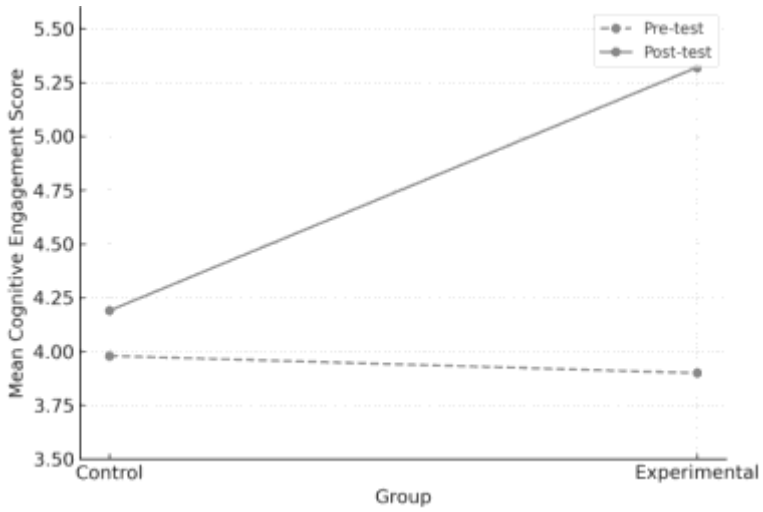

Figure 1. Change in cognitive engagement scores across time by group

However, these findings should be interpreted with some caution, as self-report measures may reflect learners' perceptions rather than their actual observed engagement.

The influence of neuroscience-informed instruction on EFL learners' executive function

Baseline EF scores were similar across groups (Table 6). Following the intervention, both groups improved, although the experimental group demonstrated a larger mean score.

Table 6. Descriptive statistics for executive function by group and time

Group	Time	M	SD	95% CI (Lower–Upper)	Skewness	Kurtosis
Control	Pre-test	2.84	0.20	2.72–2.96	0.31	-1.29
Experimental	Pre-test	2.80	0.22	2.67–2.93	0.68	-0.63
Control	Post-test	2.99	0.25	2.85–3.13	0.46	0.10
Experimental	Post-test	3.80	0.22	3.68–3.93	0.14	-1.22

Assumptions for the mixed-design ANOVA were again met (see Table 7). Tests of normality were nonsignificant, the variances were homogeneous, and the covariance matrices were equivalent in groups. Because there were only two repeated measurements, the assumption of sphericity was also satisfied.

Table 7. Assumption tests summary for executive function

Test	Pre-test *p*	Post-test *p*	Interpretation
Shapiro–Wilk (Control)	.263	.635	Normal
Shapiro–Wilk (Experimental)	.172	.628	Normal
Levene's Test	.850	.781	Equal variances
Box's M Test	—	.682	Equal covariances
Sphericity	—	Met	2 time points

Mixed-design ANOVA results for executive function are reported in Table 8. There was a significant main effect of Time, $F(1, 26) = 1052.04$, $p < .001$, $\eta^2 = .98$, showing that EF scores increased for both groups across the study period. The Time × Group interaction was also significant, $F(1, 26) = 566.19$, $p < .001$, $\eta^2 = .96$, indicating that the improvement was greater for the NII group. Pairwise comparisons (Table 9) showed a significant difference between groups at post-test (mean difference = 0.39, $p < .001$). The experimental group increased from M = 2.80 at pretest to M = 3.80 at post-test, whereas the control group increased more modestly, from M = 2.84 to M = 2.99. These results indicate that participation in NII was associated with higher scores in planning, monitoring, inhibitory control, and motivational regulation. However, because the sample was small and intact classes were used, these findings should be treated as tentative and interpreted with caution.

Table 8. Mixed ANOVA and between-subjects results for executive function

Source	df	F	Sig.	Partial η^2
Time	1, 26	1052.04	.000	.976
Time × Group	1, 26	566.19	.000	.956
Group (Between-Subjects)	1, 26	21.90	.000	.457

Table 9. Estimated marginal means and pairwise comparisons for executive function

Comparison	Mean Diff.	SE	*p*	95% CI (Lower–Upper)
Experimental > Control	0.39	0.08	.000	0.22–0.56
Post-test > Pre-test	0.58	0.02	.000	0.54–0.62

Figure 2 displays changes in executive function from pretest to post-test. As with cognitive engagement, both groups improved, but the experimental group showed a more noticeable upward trend than the control group.

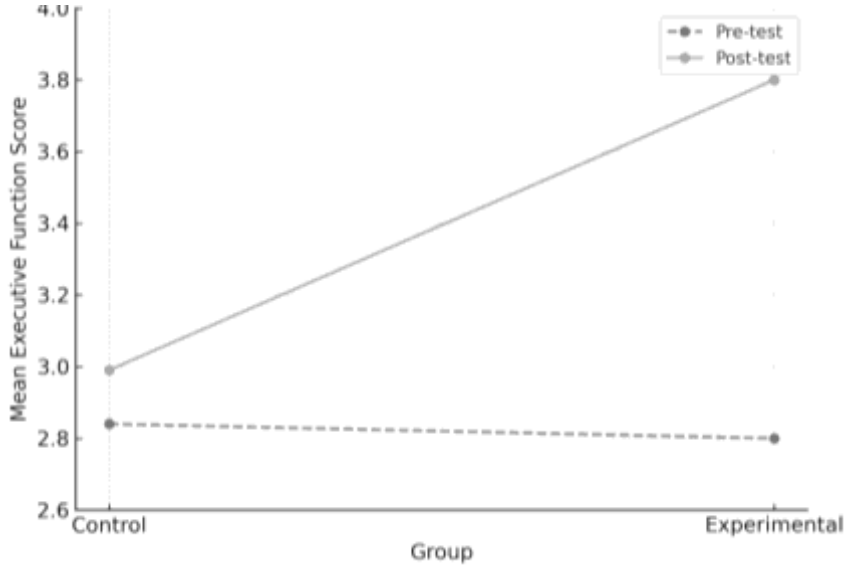

Figure 2. Change in executive function scores across time by group.

Taken together, learners who received NII showed stronger developments than those who were taught through traditional methods on both outcome measures. The similar pattern observed in both cognitive engagement and executive function may suggest that structured and reflective instructional practices are associated with higher levels of cognitive involvement. However, the size of the effects may also be influenced by the specific classroom context and other uncontrolled factors. Therefore, these findings should be confirmed in future studies with larger samples and more rigorous research designs.

Discussion

Neuroscience-informed instruction and cognitive engagement

The pattern of results suggests that learners exposed to NII experienced higher levels of cognitive engagement compared with those in conventional instruction. Although both groups improved to some extent, the experimental group showed stronger progress in strategic thinking, sustained effort, and reflective monitoring. These findings can be interpreted as suggesting that engagement may

be influenced not only by task difficulty or study time, but also by the quality of instructional design (Immordino-Yang, 2015; Oakley & Sejnowski, 2021). The structured NII sequence, which included retrieval practice, spaced review, multimodal exploration, collaboration, and reflection, may have created conditions that supported deeper processing. This aligns with previous studies showing that emotionally meaningful activities, opportunities for decision-making and scaffolded reflection promote strategic and metacognitive engagement (Cheng & Zhang, 2024; Halverson & Graham, 2019; Järvelä et al., 2016). However, the magnitude of improvement observed in the present study appears to be somewhat stronger than that reported in some previous EFL-based studies, where gains in engagement were more moderate or limited to specific subcomponents. One possible explanation for this difference may relate to the structured and sustained nature of the intervention, which combined multiple NII principles rather than applying them in isolation. In addition, the Iranian EFL context, where learners are often accustomed to more teacher-centred and exam-oriented practices, may have amplified the impact of interactive and reflective instructional elements. This interpretation is supported by the large interaction effect observed in the present study ($\eta^2 = .90$), which indicates a substantial difference in the rate of change between the two groups. In line with research reporting positive effects of NII on motivation and learning persistence (Abdolmaleki & Saeedi, 2024; Bayer, 2022; Salem, 2017), the present findings suggest that cognitive engagement is partly influenced by instructional design, and is not only an individual trait.

Moreover, these findings can be viewed from the perspective of cognitive load theory. Through techniques such as chunking and short practice cycles, NII probably reduced unnecessary cognitive load and helped students focus on meaningful learning. Similar interpretations were reported in studies on scaffolding and neuro-responsive design (Gkintoni, Antonopoulou, et al., 2025; Mansouri et al., 2024). Overall, the results indicate that well-structured NII environments may help learners persist longer and use more intentional learning strategies, which are central indicators of deep engagement.

From a pedagogical perspective, these findings suggest that organizing classroom activities around retrieval, reflection, and collaboration may help support learners' sustained mental involvement, especially in contexts where passive learning practices are more common.

Neuroscience-informed instruction and executive function

The observed differences between groups suggest that NII may be associated with improvements in executive function. Improvements were especially strong in planning, monitoring, and inhibitory control that are important for goal-directed language learning. These findings support the idea that EF develops through repeated chances to plan, check progress, change strategies, and control impulses during demanding learning tasks (Diamond, 2013; Zelazo, 2015). These findings may indicate that EF skills are more flexible than traditionally assumed. Instead, they may respond to teaching conditions more than is sometimes assumed. In the NII intervention, learners took part in goal setting, staged collaborative work, and structured reflection. These activities likely required them to manage their attention and evaluate their performance. This may suggest that instructional design can influence not only language development but also learners' cognitive regulation

processes. This interpretation is in line with studies showing that guided practice and meaningful interaction can support the development of EF (Diamond & Lee, 2011; Yao et al., 2024).

Also, it is important to note that most studies on EF in language learning have been correlational, mainly examining links between bilingualism and EF rather than classroom-based interventions (Musskopf & Barbosa, 2022; Treffers-Daller et al., 2020). The present study may extend this line of research by providing preliminary evidence that executive function can be influenced in regular EFL classrooms when instruction includes structured reflection and self-regulatory activities.

Integrating the two findings

When these findings are considered together, they may point to a possible explanatory pathway. It is possible that NII first enhances cognitive engagement, which may then create conditions in which executive function is more actively involved. This interpretation appears to be consistent with theoretical perspectives from self-regulated learning and educational neuroscience that view cognition and emotion as connected and mutually supportive processes rather than separate ones (Immordino-Yang, 2015; Vygotsky, 1978). Although the present study cannot make strong causal claims, the similar patterns in both constructs suggest that engagement should be studied not only as a learning outcome, but also as a possible mechanism that links instruction with cognitive regulation. Overall, these interpretations suggest that instructional approaches informed by cognitive and emotional processes may influence not only how learners engage with language tasks but also how they regulate their thinking during learning.

Conclusion

This study examined how NII may influence Iranian EFL learners' cognitive engagement and executive function. The results indicated that students who received NII reported higher levels of cognitive engagement and executive function compared to those in the control group. Therefore, the overall pattern of the findings suggests that NII may have value in supporting learners' cognitive engagement and executive function. Although these findings should be interpreted carefully because of the quasi-experimental design and small sample size, they may suggest that emotionally meaningful and reflective instruction may support learners' mental involvement and self-regulation in language learning. In this sense, the study highlights the possible role of instructional design in shaping not only language learning outcomes but also learners' cognitive and self-regulatory processes.

Several implications arise for classroom practice. First, using elements such as spaced review, retrieval practice, multimodal activities, and emotionally relevant tasks may help create learning environments that keep students' attention and encourage deeper processing. Instead of focusing mainly on test-driven routines, teachers may benefit from incorporating activities that promote flexible thinking, reflection, and metacognitive awareness. Second, teacher education programs may consider introducing key ideas from educational neuroscience. These ideas should not be treated as strict methods, but as tools that help teachers make informed decisions. A better understanding of how cognitive engagement and executive control work together can support teachers in designing tasks that are manageable

but still challenging. Ongoing professional development and reflective practice may help teachers gradually adopt NII-aligned approaches.

Third, curriculum planners may consider including activities that intentionally exercise executive skills such as planning, monitoring, task-switching, and self-evaluation in meaningful communicative tasks. Also, assessment practices may move beyond only measuring language performance and include indicators of engagement and self-regulation. Overall, the findings support the idea that cognitive engagement and executive function are dynamic capacities that can be developed through thoughtful instructional design. More broadly, these implications suggest that language instruction may benefit from moving toward approaches that integrate cognitive, emotional, and regulatory aspects of learning rather than treating them as separate components.

This study offers some directions for future research. Future studies with larger and more diverse samples may help increase generalizability, and randomized designs would help strengthen causal claims. Future research may also examine which specific components of NII contribute most to improvements in cognitive engagement, as the present study implemented multiple strategies simultaneously. In particular, it would be useful to isolate elements such as retrieval practice, reflection, or collaborative activities to determine their relative contribution to learners' engagement. It would also be important to investigate whether these effects can be sustained over longer instructional periods and across different phases of learning.

It would be useful to examine NII in different ages, genders, proficiency levels, and instructional settings, as these factors may influence how learners engage with and respond to instruction. In addition, mixed-methods studies using interviews or learner journals could provide deeper insight into how students experience NII. Future research is recommended to complement self-report measures with performance-based assessments or observational data in order to better capture actual learning outcomes alongside learners' perceptions. Where appropriate, complementary methods such as eye-tracking or neurocognitive measures may help explain how engagement and executive function change over time.

Future studies should explore how regular classroom teachers use NII in real school contexts, including opportunities, challenges, and professional learning needs. Such investigations can guide more sustainable teacher development and support the careful, thoughtful integration of neuroscience-informed ideas into everyday classroom practice. At the same time, future studies should continue to examine NII critically to ensure that its application remains grounded in both empirical evidence and pedagogical relevance.

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