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ORIGINAL RESEARCH PAPER

The power of time: how spacing techniques revolutionize ESP vocabulary learning online

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ABSTRACT

Background and Objectives: The growing influence of Information and Communication Technology (ICT) has considerably altered educational practices, particularly in language learning contexts. In English for Specific Purposes (ESP) courses, mastering technical vocabulary is a fundamental yet challenging requirement due to the specialized nature of the content and learners' limited exposure beyond academic settings. Traditional vocabulary instruction methods often provide insufficient repetition and lack flexibility, which can negatively affect retention and long-term learning. In response to these challenges, technology-enhanced learning tools have emerged as effective alternatives for supporting vocabulary development. Digital flashcards, especially when used through online platforms, offer structured repetition, learner autonomy, and increased engagement. However, despite their widespread use, there is limited empirical research examining the effectiveness of digital flashcards implemented at predetermined time intervals in ESP contexts. Therefore, this mixed-methods study aimed to investigate the effects of using ICT-based digital flashcards with spaced repetition on undergraduate ESP learners' acquisition of technical vocabulary. Additionally, the study explored learners' perceptions of using Quizlet as a technology-supported instructional tool.

Materials and Methods: The study employed a mixed-methods research design integrating quantitative and qualitative data to provide a comprehensive understanding of the research objectives. The participants were 60 undergraduate students enrolled in ESP courses, who were randomly assigned to an experimental group and a control group. Before the instructional intervention, both groups completed a background questionnaire and a technical vocabulary pre-test to ensure comparability in terms of prior knowledge. During the treatment phase, the experimental group learned technical vocabulary through digital flashcards delivered via an online platform at planned and systematic time intervals based on spaced learning principles. In contrast, the control group received conventional vocabulary instruction without the use of digital flashcards or ICT-based tools. Data collection instruments included technical vocabulary pre- and post-tests, post-treatment questionnaires, and semi-structured interviews. Quantitative data were analyzed using paired-samples t-tests to examine within-group changes and an independent-samples t-test on gain scores to compare the magnitude of vocabulary improvement between the two groups. Qualitative interview data were analyzed through content analysis using NVivo software.

Findings: The results of the quantitative analysis showed that the experimental group achieved significantly greater vocabulary gains than the control group, as confirmed by an independent-samples t-test on gain scores. These findings indicate that the use of digital flashcards with spaced intervals had a positive and statistically significant effect on ESP learners' vocabulary acquisition. Learners who experienced repeated and structured exposure to technical terms demonstrated higher levels of retention and recall. Moreover, the results suggested that Quizlet functioned as an effective and reliable ICT-based platform for facilitating vocabulary learning. The qualitative findings further supported the quantitative results, revealing that learners held positive attitudes toward the use of digital flashcards. Participants reported increased motivation, improved engagement, and greater control over their learning process. They also noted that spaced repetition helped reduce cognitive load and made learning complex technical vocabulary more manageable.

Conclusions: The findings of this study demonstrate that integrating ICT-based tools, particularly digital flashcards with spaced repetition, can effectively enhance technical vocabulary learning in

ESP contexts. From a technology of education perspective, the results highlight the pedagogical value of online learning platforms in promoting learner autonomy and improving vocabulary retention. This study contributes to the field of educational technology by providing empirical evidence for the effectiveness of interval-based digital flashcards in ESP instruction. It is recommended that ESP instructors and curriculum designers incorporate technology-enhanced vocabulary learning strategies into their courses to achieve more effective and sustainable learning outcomes.

NUMBER OF REFERENCES 32
NUMBER OF FIGURES 0
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مقاله پژوهشی

قدرت زمان: چگونه فنون فاصله‌گذاری یادگیری واژگان ESP را در محیط آنلاین متحول می‌کنند

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چکیده

پیشینه و اهداف: گسترش روزافزون فناوری اطلاعات و ارتباطات (فاوا) تأثیر قابل‌توجهی بر شیوه‌های آموزشی، به‌ویژه در بافت‌های آموزش زبان، گذاشته است. در دوره‌های زبان انگلیسی برای اهداف ویژه (ESP)، تسلط بر واژگان تخصصی یک ضرورت اساسی اما چالش‌برانگیز محسوب می‌شود؛ زیرا ماهیت تخصصی محتوا و محدود بودن مواجهه زبان‌آموزان با آن خارج از محیط‌های دانشگاهی، فرایند یادگیری را دشوار می‌سازد. روش‌های سنتی آموزش واژگان غالباً تکرار کافی را فراهم نمی‌کنند و از انعطاف‌پذیری لازم برخوردار نیستند؛ امری که می‌تواند بر ماندگاری و یادگیری بلندمدت تأثیر منفی بگذارد. در پاسخ به این چالش‌ها، ابزارهای یادگیری تقویت‌شده با فناوری به‌عنوان گزینه‌هایی مؤثر برای حمایت از رشد واژگانی مطرح شده‌اند. فلش‌کارت‌های دیجیتال، به‌ویژه هنگام استفاده از سکوهای آنلاین، امکان تکرار ساختاریافته، خودمختاری یادگیرنده و افزایش درگیری شناختی را فراهم می‌کنند. با وجود کاربرد گسترده این ابزارها، پژوهش‌های تجربی محدودی درباره اثربخشی فلش‌کارت‌های دیجیتال اجراشده در فواصل زمانی از پیش تعیین‌شده در بافت‌های انگلیسی برای اهداف ویژه وجود دارد. ازاین‌رو، پژوهش حاضر با رویکرد روش ترکیبی، با هدف بررسی تأثیر استفاده از فلش‌کارت‌های دیجیتال مبتنی بر فناوری اطلاعات و ارتباطات همراه با تکرار فاصله‌دار بر یادگیری واژگان تخصصی دانشجویان کارشناسی انگلیسی برای اهداف ویژه انجام شد. همچنین، این مطالعه به بررسی ادراک زبان‌آموزان از کاربرد Quizlet به‌عنوان یک ابزار آموزشی پشتیبانی‌شده با فناوری پرداخت.

روش‌ها: این پژوهش از طرح پژوهش ترکیبی بهره گرفت و داده‌های کمی و کیفی را به‌منظور دستیابی به درکی جامع از اهداف پژوهش تلفیق کرد. شرکت‌کنندگان شامل شصت دانشجوی کارشناسی مشغول به تحصیل در دوره‌های انگلیسی برای اهداف ویژه بودند که به‌صورت تصادفی در دو گروه آزمایشی و کنترل جای‌گذاری شدند. پیش از مداخله آموزشی، هر دو گروه پرسشنامه پیشینه و آزمون پیش‌آزمون واژگان تخصصی را تکمیل کردند تا از همگنی آن‌ها از نظر دانش پیشین اطمینان حاصل شود. در مرحله اجرا، گروه آزمایشی واژگان تخصصی را از طریق فلش‌کارت‌های دیجیتال ارائه‌شده در یک پلتفرم آنلاین و در فواصل زمانی برنامه‌ریزی‌شده و منظم مبتنی بر اصول یادگیری فاصله‌دار فراگرفت. در مقابل، گروه کنترل آموزش متعارف واژگان را بدون استفاده از فلش‌کارت‌های دیجیتال یا ابزارهای مبتنی بر فاوا دریافت کرد. ابزارهای گردآوری داده شامل پیش‌آزمون و پس‌آزمون واژگان تخصصی، پرسشنامه پس از مداخله و مصاحبه‌های نیمه‌ساختاریافته بود. داده‌های کمی با استفاده از آزمون‌های t برای مقایسه نتایج یادگیری واژگان دو گروه تحلیل شد و داده‌های کیفی حاصل از مصاحبه‌ها از طریق تحلیل محتوا با استفاده از نرم‌افزار NVivo مورد بررسی قرار گرفت.

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یافته‌ها: نتایج تحلیل کمی نشان داد که گروه آزمایشی پیشرفت واژگانی معنادارتری نسبت به گروه کنترل کسب کرد، همانطور که آزمون مستقل t بر روی نمرات تفاضل تایید کرد. این یافته‌ها بیانگر آن است که استفاده از فلش‌کارت‌های دیجیتال با فواصل زمانی برنامه‌ریزی‌شده، تأثیر مثبت و معناداری بر یادگیری واژگان زبان‌آموزان انگلیسی برای اهداف ویژه داشته است. زبان‌آموزانی که در معرض مواجهه تکراری و ساختاریافته با اصطلاحات تخصصی قرار گرفتند، سطوح بالاتری از ماندگاری و یادآوری را نشان دادند. افزون بر این، نتایج حاکی از آن بود که Quizlet به‌عنوان یک پلتفرم مبتنی بر فاوا، ابزار مؤثر و قابل اعتمادی برای تسهیل یادگیری واژگان عمل کرده است. یافته‌های کیفی نیز نتایج کمی را تأیید کرد و نشان داد که زبان‌آموزان نگرش‌های مثبتی نسبت به استفاده از فلش‌کارت‌های دیجیتال داشتند. شرکت‌کنندگان افزایش انگیزش، بهبود درگیری یادگیری و کنترل بیشتر بر فرایند یادگیری خود را گزارش کردند. آن‌ها همچنین اشاره کردند که تکرار فاصله‌دار به کاهش بار شناختی کمک کرده و یادگیری واژگان تخصصی پیچیده را قابل مدیریت‌تر ساخته است.

نتیجه‌گیری: یافته‌های این پژوهش نشان می‌دهد که ادغام ابزارهای مبتنی بر فاوا، به‌ویژه فلش‌کارت‌های دیجیتال همراه با تکرار فاصله‌دار، می‌تواند به‌طور مؤثری یادگیری واژگان تخصصی را در بافت‌های انگلیسی برای اهداف ویژه تقویت کند. از منظر فناوری آموزشی، نتایج بر ارزش تربیتی پلتفرم‌های یادگیری آنلاین در ارتقای خودمختاری یادگیرنده و بهبود ماندگاری واژگان تأکید دارد. این مطالعه با ارائه شواهد تجربی درباره اثربخشی فلش‌کارت‌های دیجیتال مبتنی بر فواصل زمانی در آموزش انگلیسی برای اهداف ویژه ،به حوزه فناوری آموزشی کمک می‌کند. پیشنهاد می‌شود مدرسان انگلیسی برای اهداف ویژه و طراحان برنامه درسی، راهبردهای یادگیری واژگان تقویت‌شده با فناوری را در دوره‌های خود ادغام کنند تا به نتایج یادگیری مؤثرتر و پایدارتر دست یابند.

Introduction

The integration of Information and Communication Technology (ICT) into language education has reshaped instructional practices and redefined how learners engage with linguistic input. Recent advancements in digital learning environments have shifted the focus from teacher-centered transmission models toward learner-centered, technology-mediated pedagogies that promote autonomy, sustained engagement, and data-driven feedback [1-2]. In addition, recent syntheses of research suggest that technology integration in language classrooms can significantly enhance learner interaction and self-regulated learning when pedagogically grounded [3-4]. Within applied linguistics, the growing emphasis on evidence-based instructional design has highlighted the importance of aligning technological tools with established cognitive learning principles. As a result, vocabulary instruction—long recognized as a cornerstone of second and foreign language proficiency—has increasingly been supported through digital platforms that enable repeated exposure, retrieval practice, and adaptive review mechanisms [5-6].

Vocabulary knowledge constitutes a foundational dimension of communicative competence, directly influencing learners' reading comprehension, listening ability, speaking fluency, and academic achievement. In English for Specific Purposes (ESP) contexts, lexical competence becomes even more critical because learners must acquire discipline-specific terminology that occurs with limited frequency outside specialized domains [7-8]. Research on vocabulary acquisition further emphasizes that systematic and technology-supported lexical instruction can strengthen depth of processing and long-term retention, particularly when digital tools are integrated into structured learning environments [9]. The technical and often abstract nature of ESP vocabulary presents substantial learning challenges, particularly in contexts where learners have restricted exposure to authentic input. Consequently, relying solely on incidental vocabulary acquisition is insufficient; intentional, systematically structured lexical

instruction is necessary to facilitate durable retention and productive use [10].

From a cognitive perspective, vocabulary acquisition is incremental and requires multiple encounters distributed across time. One of the most robust findings in memory research—the spacing effect—demonstrates that learning episodes spaced over intervals yield stronger long-term retention than massed practice conducted within a single session [11-12-13]. Spaced retrieval enhances memory consolidation by strengthening neural encoding pathways and reducing cognitive overload, thereby increasing both accuracy and durability of recall [14]. In second language acquisition research, retrieval practice combined with distributed scheduling has been shown to significantly improve vocabulary retention compared to repeated exposure without temporal spacing [15].

Digital flashcard applications provide an ideal environment for operationalizing spacing principles within language classrooms. Platforms such as Quizlet incorporate automated review cycles, time-controlled repetition, gamified testing modes, and mobile accessibility, all of which may enhance both cognitive processing and learner motivation [16-2]. Unlike traditional paper-based flashcards, digital systems can algorithmically schedule review sessions, monitor performance, and adjust repetition intervals to optimize learning efficiency. However, despite the well-documented benefits of spaced practice in cognitive psychology, empirical investigations examining how digitally scheduled spacing influences ESP learners' technical vocabulary development remain limited.

Addressing this gap is important for both theoretical understanding and practical application. Examining spaced digital vocabulary learning in ESP contexts connects research on cognitive memory with effective technology-enhanced language learning. Understanding learning outcomes and learner perceptions allows for informed curriculum design, enabling educators to purposefully integrate digital tools to support vocabulary instruction. In higher education, where time constraints and demanding subject matter often limit opportunities for repeated vocabulary practice, identifying efficient, research-backed instructional strategies is very essential. Recent empirical evidence suggests that retrieval-based instructional approaches, especially those employing systematic spacing improve long-term vocabulary retention in second language contexts [17].

Although the effectiveness of spaced learning was approved in recent years [18-19-20], the present mixed-methods research is aimed at examining the impact of spaced learning on the enhancement of ESP vocabulary using Quizlet digital flashcards. Additionally, the study sought to explore the following research inquiries:

- Is spacing technical vocabulary learning through digital flashcards more effective than massed learning?
- What are the perceptions of learners in the experimental group regarding the implementation of spaced retrieval?
- What are the ESP learners' attitudes toward using Quizlet digital flashcards with specific intervals for learning technical vocabulary?

Review of Related Literature

Theoretical Background

The present study is grounded in two complementary theoretical perspectives that explain learners' acceptance of digital learning tools and their engagement in structured vocabulary learning environments: the Technology Acceptance Model (TAM) and the

Theory of Planned Behavior (TPB). Rather than adopting these frameworks as isolated models, the study integrates them to explain how perceived usefulness, perceived ease of use, behavioral intentions, and perceived control may influence learners' engagement with spaced digital flashcards.

Recent extensions of TAM emphasize that learners' adoption of educational technologies is largely determined by their perceptions of usefulness, usability, and motivational affordances [3-21]. Empirical investigations in higher education settings further indicate that students' sustained engagement with digital learning platforms is strongly predicted by perceived usefulness and self-efficacy beliefs [22]. In language learning contexts, perceived usefulness often relates to improved performance, efficiency, and long-term retention, while perceived ease of use relates to reduced cognitive load and accessibility of the platform [2]. When learners perceive digital tools as beneficial and manageable, their intention to use such technologies increases significantly.

Similarly, the Theory of Planned Behavior posits that behavior is driven by behavioral intentions shaped by attitudes, subjective norms, and perceived behavioral control [23]. In digitally mediated vocabulary learning environments, perceived behavioral control may manifest as learners' belief in their ability to regulate their study schedules, manage repetition intervals, and successfully retrieve vocabulary items. Recent research has shown that students' intention to continue using educational technologies is strongly associated with motivational beliefs and perceived autonomy [2-4].

By integrating TAM and TPB, the present study provides a theoretical basis for examining not only the effectiveness of spaced digital vocabulary learning but also learners' perceptions and attitudes toward scheduled repetition in Quizlet. These frameworks justify the inclusion of qualitative data exploring motivation, engagement, and perceived learning enhancement.

Spaced Retrieval and Vocabulary Learning

The spacing effect, one of the most robust findings in cognitive psychology, suggests that distributed learning episodes result in stronger long-term retention than massed practice [11-12]. Spaced retrieval enhances memory consolidation by allowing forgetting to occur between sessions, thereby strengthening retrieval pathways when information is reactivated [24].

In second language acquisition, retrieval-based practice combined with temporal distribution has demonstrated significant gains in vocabulary retention compared to repeated exposure without spacing [15]. Experimental research has also demonstrated that expanding retrieval schedules produces more durable vocabulary retention than fixed or massed repetition patterns, particularly when practice sessions are distributed across days rather than within a single session [17]. Meta-analytic evidence indicates that distributed practice yields medium to large effect sizes for long-term vocabulary retention, particularly when retrieval is effortful and feedback is immediate [14].

Although the cognitive advantages of spaced learning are well established, fewer studies have examined how spacing principles operate within digital vocabulary platforms that algorithmically schedule review sessions. As digital environments allow precise control over interval timing and frequency, they may optimize spacing more effectively than traditional classroom-based repetition. However, empirical research specifically targeting ESP learners and technical vocabulary

within digitally scheduled spacing remains limited. This gap highlights the need for research that combines cognitive principles with technology-enhanced language learning.

Vocabulary Learning in ESP Contexts

Vocabulary knowledge is widely recognized as a core component of language proficiency, particularly in academic and professional domains [25]. In ESP contexts, learners must acquire discipline-specific lexical items that are often abstract, low-frequency outside the field, and conceptually dense [7]. Technical vocabulary plays a decisive role in enabling learners to comprehend specialized texts and participate in professional discourse communities [8].

Contemporary perspectives emphasize that vocabulary acquisition is incremental and requires repeated, meaningful encounters across time [10-9]. Incidental exposure alone is insufficient for mastering technical terminology; instead, intentional and structured instructional approaches are necessary.

Moreover, digital learning environments offer expanded affordances for repeated exposure, multimodal presentation, and learner-controlled pacing. Research has shown that technology-mediated vocabulary learning can enhance engagement, autonomy, and retention when grounded in cognitive principles such as retrieval practice and spacing [5-2]. Despite these advances, the intersection of ESP vocabulary, digital flashcards, and algorithmically scheduled spacing remains underexplored.

Digital Flashcards and Quizlet

Digital flashcard applications operationalize key principles of vocabulary learning, including form–meaning mapping, retrieval practice, and distributed exposure. Recent empirical investigations suggest that digital flashcards are effective tools for improving vocabulary retention, particularly when they incorporate adaptive scheduling and gamified features [6-16].

Unlike traditional paper-based flashcards, digital platforms such as Quizlet provide automated review cycles, performance tracking, and mobile accessibility. These features may enhance learner engagement and encourage sustained practice. A recent meta-analysis on technology-enhanced vocabulary learning confirmed that digital tools produce significant positive effects compared to traditional methods, especially when repetition is structured and interactive [2].

However, while previous studies have examined digital flashcards in general EFL settings [4-6-16], relatively limited research has investigated their effectiveness for technical vocabulary acquisition in ESP contexts, particularly through experimentally manipulated spacing intervals. Furthermore, the role of learners' perceptions, motivation, and competitive engagement in such environments requires further qualitative exploration.

ICT in ESP and Research Gap

ICT integration in ESP classrooms has been associated with increased learner autonomy, improved access to authentic materials, and enhanced professional relevance [26]. Nevertheless, much of the research on ICT in ESP focuses on general digital integration rather than cognitively principled instructional design.

Although separate bodies of research exist on (a) spacing effect in vocabulary learning, (b) digital flashcards in language education, and (c) ICT use in ESP contexts, there is a notable lack of mixed-method studies examining the combined impact of digitally scheduled spacing on technical vocabulary development within

ESP settings.

The present study addresses this gap by experimentally comparing spaced and massed vocabulary learning through Quizlet digital flashcards while simultaneously exploring learners' perceptions and attitudes. By integrating cognitive theory, technology acceptance models, and ESP pedagogy, this study contributes to both theoretical understanding and pedagogical practice in technology-enhanced language learning.

Method

Participants

The participants initially consisted of 90 Iranian undergraduate students majoring in Architecture, all enrolled in an ESP course. The cohort included both male and female students, aged between 19 and 24, who were in their second or third academic year. To ensure homogeneity in general English proficiency, an Oxford Placement Test was administered. Based on the test results, 60 learners who met the intermediate level criterion (B1 according to the Common European Framework of Reference [CEFR]) were selected as the final sample. The selected participants were then assigned to two intact groups: an experimental group (n = 30) and a control group (n = 30). Participation was voluntary and informed consent was obtained from all individuals involved.

Instruments

Placement Test

An Oxford Placement Test consisting of 50 multiple-choice items assessing grammar and vocabulary knowledge was administered to determine participants' general language proficiency. The test duration was 40 minutes (averaging 48 seconds per item). According to the test guidelines, scores above 31 correspond to the intermediate (B1) level. Only those meeting this criterion were included in the study.

Technical Vocabulary Tests

To measure vocabulary development, a researcher-developed technical vocabulary test was administered as both a pre-test and a post-test. The tests included 30 multiple-choice items derived from Technical English for Architects.

To establish content and construct validity, the instrument was piloted with 120 EFL learners at another university who shared similar characteristics with the target population. Internal consistency was calculated separately for each administration, yielding a Cronbach's alpha of 0.82 for the pre-test and 0.86 for the post-test, indicating high reliability across both measurements. Both pre- and post-tests were scored independently by two raters to reduce scoring bias, and the average of the two scores was used as the final score.

Post-treatment Questionnaire

The post-treatment questionnaire, adopted from Lotfolahi and Salehi [19], was administered immediately after the post-test to explore the perceptions of the experimental group about using spaced digital flashcards. It addressed experiences and attitudes formed during the intervention, aiming to examine the effects of the spacing technique on learning target vocabulary. The questionnaire consisted of 14 Likert-scale items rated on a five-point scale (1 = Strongly Agree to 5 = Strongly Disagree). It was completed by all 30 participants in the experimental group. To prevent misunderstanding, the questionnaire was translated into Persian. The translated version underwent expert validation by bilingual specialists to ensure linguistic

accuracy, conceptual equivalence, and cultural appropriateness.

Semi-structured Interview

To obtain in-depth qualitative data, semi-structured interviews were conducted with 10 participants purposively selected from the experimental group to represent a range of final vocabulary test scores (high, medium, low), ensuring diverse perspectives on the learning experience. The interviews aimed to explore participants' attitudes, motivation, and perceptions regarding the use of Quizlet digital flashcards with scheduled intervals. All interviews were audio-recorded and later transcribed for analysis.

The interview protocol consisted of four open-ended questions (see Appendix) designed to collectively deepen and complement the quantitative findings across all three research questions. Rather than mapping each question to a single research question in isolation, the questions were constructed to allow participants to reflect on interconnected aspects of their learning experience—including motivation, engagement, perceived challenge, and vocabulary retention—which together inform all three research questions. This design ensured that the qualitative data captured the complexity and interrelatedness of learners' experiences with spaced digital flashcard practice, while allowing participants the freedom to elaborate on their unique perspectives. The integration of responses across all four questions enabled the researchers to identify recurrent themes that cut across the study's research objectives, thereby strengthening the triangulation of quantitative and qualitative findings.

Data Collection Procedure

Ethical approval for the study was obtained from the English Department of Pars Higher Education Institute, Tehran, Iran. Participation was voluntary, and informed consent was obtained from all students. Following the administration of the placement test, 60 intermediate learners were selected and assigned to experimental and control groups. The intervention lasted six weeks, with classes held twice a week for two hours. Both groups were taught by the same instructor to control for teacher-related variables. At the beginning of the study, both groups took the technical vocabulary pre-test under standardized conditions. During the intervention period, both groups used Quizlet digital flashcards to learn technical vocabulary. However, the experimental group was required to follow a structured spaced schedule, reviewing vocabulary at two-day intervals. In contrast, the control group used Quizlet without predetermined intervals. At the end of the treatment, both groups completed the post-test under identical conditions. Afterward, a post-treatment questionnaire was administered only to the experimental group to gather data on their perceptions of the spaced digital flashcard use. This questionnaire was not given to the control group because their instruction did not involve a spaced schedule, making the questions irrelevant to their experience. Finally, semi-structured interviews were conducted with 10 participants from the experimental group to gain deeper insights into their learning experiences. A standardized protocol was followed to ensure consistency and depth across all sessions. Each interview was conducted individually in a quiet, private setting to minimize distractions. Before the interview, participants were briefed on the purpose of the study, assured of confidentiality, and provided informed consent. The interviews began with a brief, neutral opening question to establish rapport. The interviewer then followed the guiding questions (see Appendix),

allowing participants to speak freely while using prepared prompts (e.g., “Can you elaborate on that?” or “Could you give an example?”) to explore responses in greater depth when necessary. Each interview lasted approximately 20–30 minutes.

Data Analysis

A mixed-method approach was employed for data analysis. Quantitative data were entered into SPSS. Before conducting inferential statistics, assumption testing was performed. The normality of score distributions for both groups was examined using the Shapiro–Wilk test, and the homogeneity of variances was assessed through Levene’s Test of Equality of Variances. Descriptive statistics, including means and standard deviations, were calculated to summarize participants’ performance on the pre- and post-tests. To examine within-group changes from pre-test to post-test, paired-samples t-tests were conducted separately for the experimental and control groups. In addition, to compare the effectiveness of spaced versus non-spaced digital flashcard practice between the two groups, gain scores (post-test minus pre-test) were calculated for each participant. An independent-samples t-test was then performed on these gain scores to determine whether the magnitude of improvement differed significantly between the experimental and control groups. This approach was adopted because comparing raw post-test scores alone does not account for potential pre-existing differences in baseline vocabulary knowledge, whereas gain score analysis directly measures the amount of change attributable to the intervention. Statistical significance was set at $p < .05$. For qualitative analysis, interview transcripts were imported into NVivo software and analyzed using thematic content analysis. An inductive coding procedure was applied to identify recurring themes related to motivation, engagement, competition, and perceived vocabulary improvement.

For qualitative analysis, interview transcripts were imported into NVivo software to facilitate systematic data management and coding. The analysis followed the six-phase thematic analysis protocol proposed by Braun and Clarke [27] to ensure rigor and transparency. First, the researchers familiarized themselves with the data by reading and re-reading the transcripts. Second, an inductive coding procedure was applied to generate initial codes for meaningful segments of text. Third, these codes were collated into potential themes related to motivation, engagement, competition, and perceived vocabulary improvement. Fourth, the themes were reviewed against the coded extracts and the entire dataset to ensure they accurately reflected the participants’ experiences. Fifth, the specific nature of each theme was defined and named. Finally, the analysis was written up, linking the identified themes back to the study’s research questions. This structured approach ensured that the findings were grounded in the data rather than researcher bias.

Design of the Study

The present study adopted a quasi-experimental mixed-methods design to examine the effect of digitally delivered flashcards via Quizlet on the acquisition of technical vocabulary under scheduled spaced intervals. Due to the use of intact classroom groups, random assignment was not feasible; therefore, control and experimental groups were compared within a quasi-experimental framework. Quantitative data were collected through pre- and post-tests measuring learners’ vocabulary knowledge, along with a structured questionnaire assessing their perceptions of spaced digital practice.

To gain deeper insights into the intervention's impact, qualitative data were gathered through semi-structured interviews with participants in the experimental group. The integration of quantitative and qualitative findings allowed for triangulation and provided a more comprehensive understanding of how digitally scheduled spacing influenced vocabulary development and learner perceptions.

Results and Findings

Descriptive Statistics

To provide an initial overview of participants' performance, descriptive statistics were calculated for both the control and experimental groups in the pre-test and post-test phases. The results are presented in Table 1.

As presented in Table 1, the pre-test mean scores of the control group (M = 17.88, SD = 4.87) and the experimental group (M = 18.52, SD = 5.35) were closely aligned, indicating a comparable level of technical vocabulary knowledge before the intervention. This similarity suggests baseline equivalence between the two groups.

In the post-test phase, however, a clear divergence emerged. While the control group showed only a marginal increase in mean score (M = 18.04, SD = 4.03), the experimental group demonstrated a substantial improvement (M = 24.00, SD = 2.70). Additionally, the reduction in standard deviation in the experimental group suggests more homogeneous performance following the intervention. These descriptive findings indicate a notable gain in vocabulary achievement among learners exposed to scheduled spaced practice through Quizlet, warranting further inferential analysis to determine statistical significance.

Assumption Testing

Normality Tests

Before conducting parametric analyses, the assumption of normality was examined using the Kolmogorov–Smirnov and Shapiro–Wilk tests. These tests were applied separately to the pre-test and post-test scores of both groups to determine whether the data were normally distributed. The results are presented in Table 2.

Table 1: Descriptive Statistics for Pre-test and Post- test Scores

Group		N	Mean	Std. Deviation	Std. Error Mean
Pre-T	Control	30	17.88	4.87	0.975
	Experimental	30	18.52	5.35	1.068
Post-T	Control	30	18.04	4.03	0.805
	Experimental	30	24.00	2.70	0.539

Table 2: Kolmogorov–Smirnov and Shapiro–Wilk Tests of Normality

Group		Kolmogorov-Smirnova			Shapiro-Wilk		
		Statistic	Df	Sig.	Statistic	Df	Sig.
Pre-test	Control	0.175	30	0.092	0.950	30	0.364
	Experimental	0.144	30	0.240	0.958	30	0.461
Post-test	Control	0.165	30	0.132	0.946	30	0.346
	Experimental	0.173	30	0.109	0.925	30	0.134

As reported in Table 2, all significance values for both the Kolmogorov–Smirnov and Shapiro–Wilk tests exceeded the .05 threshold. This indicates that the pre-test and post-test scores for both the control and experimental groups did not significantly deviate from a normal distribution. Therefore, the assumption of normality was satisfied, and parametric statistical procedures were considered appropriate for subsequent analyses.

Homogeneity of Variance

Levene's test was conducted separately for the pre-test and post-test scores. Establishing variance equality at the pre-test stage confirms the statistical comparability of the two groups before the intervention (Table 3), whereas testing homogeneity at the post-test stage verifies whether the equal variances assumption required for the independent-samples t-test is satisfied (Table 4).

Table 3: Levene's Test for Equality of Variances (Pre-test Scores)

Variable	Levene Statistic	df1	df2	Sig.
Vocabulary Learning	0.15	1	58	0.152

Table 4: Levene's Test for Equality of Variances (Post-test Scores)

Variable	Levene Statistic	df1	df2	Sig.
Vocabulary Learning	2.041	1	58	0.161

The results in Table 3 reveal that Levene's test was not statistically significant (p = .152 > .05), indicating that the assumption of homogeneity of variance was satisfied for the pre-test scores. Thus, the variability of vocabulary knowledge was comparable across the control and experimental groups before the intervention.

As presented in Table 4, Levene's test for the post-test scores was not statistically significant (p = .161 > .05), suggesting that the assumption of equal variances was met. Consequently, the results corresponding to the "equal variances assumed" row of the independent-samples t-test were interpreted.

RQ One: The Effectiveness of Spaced versus Massed Vocabulary Learning through Digital Flashcards

To address the first research question—whether spacing technical vocabulary learning through digital flashcards is more effective than massed learning—both within-group and between-group comparisons were conducted.

Changes in Vocabulary Performance: Control Group

To determine whether the control group demonstrated significant improvement over time, a paired-samples t-test was conducted comparing their pre-test and post-test scores. The results are presented in Table 5.

As shown in Table 5, the paired-samples t-test revealed no statistically significant difference between the control group's pre-test and post-test scores [t (29) = -0.267, p = .801]. The 95% confidence interval for the mean difference included zero, further confirming the absence of a significant change over time. These findings indicate that vocabulary learning without structured spaced intervals did not lead to measurable improvement in the control group during the study period.

Changes in Vocabulary Performance: Experimental Group

To examine whether the experimental group demonstrated significant improvement following the intervention, a paired-samples t-test was conducted comparing pre-test and post-test scores. The results are presented in Table 6.

Table 5: Paired-Samples t-Test for the Control Group

	Paired difference							
	Mean	Std. Deviation	Std. Error Mean	95% confidence interval of the difference		T	Df	Sig. (2-tailed)
				Lower	Upper			
Pair pretest-posttest	-0.16	2.989	0.589	-1.40	1.10	-0.267	29	0.801

Table 6: Paired-Samples t-Test for the Experimental Group

	Paired difference							
	Mean	Std. Deviation	Std. Error Mean	95% confidence interval of the difference		T	Df	Sig.(2-tailed)
				Lower	Upper			
Pair pretest-posttest	-5.36	4.431	0.866	-7.48	-3.26	-6.325	29	0.001

As demonstrated in Table 6, the paired-samples t-test revealed a statistically significant difference between the experimental group's pre-test and post-test scores, $t(29) = -6.325$, $p < .001$. The 95% confidence interval for the mean difference did not include zero, indicating a reliable improvement following the intervention. The negative mean difference reflects higher post-test scores compared to pre-test scores. These findings demonstrate that participation in digitally scheduled spaced practice led to a substantial gain in technical vocabulary knowledge among learners in the experimental group.

Between-Group Comparison: Gain Score Analysis

While the within-group comparisons demonstrated that only the experimental group achieved significant pre-to-post improvement, comparing two separate p-values does not constitute a valid statistical test of between-group differences. A group may show a non-significant p-value not because it truly failed to improve but because of higher variability or smaller effect size. Therefore, to directly compare the magnitude of vocabulary gains between the two groups, gain scores were calculated for each participant by subtracting pre-test scores from post-test scores. Descriptive statistics for the gain scores are presented in Table 7.

Table 7: Descriptive Statistics for Gain Scores

Group	N	Mean Gain	Std. Deviation	Std. Error Mean
Control	30	0.16	2.99	0.546
Experimental	30	5.48	4.43	0.809

As presented in Table 7, the experimental group demonstrated a substantially larger mean gain ($M = 5.48$, $SD = 4.43$) compared to the control group ($M = 0.16$, $SD = 2.99$), indicating that learners who followed the structured spaced schedule achieved considerably greater improvement in technical vocabulary knowledge. Before conducting the between-group comparison, Levene's test was performed to assess the homogeneity of variances for the gain scores. The results are presented in Table 8.

Table 8: Levene's Test for Equality of Variances (Gain Scores)

Variable	Levene Statistic	df1	df2	Sig.
Gain Scores	3.214	1	58	.078

The result of Levene's test was not statistically significant ($p = .078 > .05$), indicating that the assumption of equal variances was met for the gain scores. Consequently, the equal variances assumed condition of the independent-samples t-test was interpreted. An independent-samples t-test was conducted to compare the gain scores of the control and experimental groups. The results are presented in Table 9.

As shown in Table 9, the independent-samples t-test revealed a statistically significant difference between the gain scores of the control and experimental groups, $t(58) = -5.456$, $p < .001$. The 95% confidence interval for the mean difference ranged from -7.27 to -3.37, indicating that the experimental group's improvement was reliably and substantially greater than that of the control group. These results confirm that digitally scheduled spaced vocabulary practice produced significantly greater vocabulary gains compared to non-spaced practice, thereby providing a robust affirmative answer to the first research question.

This gain score analysis addresses a critical methodological concern: although the pre-test means of the two groups were similar (control: M = 17.88; experimental: M = 18.52), they were not identical. By analyzing gain scores rather than raw post-test scores, the comparison directly captures the amount of change each participant experienced, thereby controlling for any baseline differences and providing a more precise estimate of the intervention effect.

RQ Two: Learners' Perceptions of Spaced Retrieval Implementation

To address the second research question—what are the perceptions of learners in the experimental group regarding the implementation of spaced retrieval—a post-intervention questionnaire was administered to the 30 participants in the experimental group. Responses were collected on a five-point Likert scale (1 = Strongly Agree to 5 = Strongly Disagree). Descriptive statistics were calculated to determine the distribution of responses across items, and one-sample t-tests were conducted to compare the mean score of each item against the neutral midpoint of the scale (M = 3). The distribution of responses is presented in Table 10.

Table 9: Independent-Samples t-Test for Comparing Gain Scores between Groups

	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI Lower	95% CI Upper
Equal variances assumed	-5.456	58	.001	-5.32	0.975	-7.27	-3.37
Equal variances not assumed	-5.456	50.4	.001	-5.32	0.975	-7.28	-3.36

Table 10: Detailed Questionnaire Results

Survey questions	1 %	2 %	3 %	4 %	5 %
1- Spatial repetition improves my word recall.	56.67	23.33	13.33	6.67	0
2- Spaced learning lessons help me retain more knowledge.	60	26.67	13.33	0	0
3- I can remember spaced vocabulary longer and faster on tests.	63.33	13.33	23.33	0	0
4- I can observe an improvement in my vocabulary through spaced repetitions.	46.67	30	16.67	6.67	0
5- Spaced-out lessons help me understand things more clearly.	40	26.67	30	3.33	0
6- Spaced-out lessons help me learn more quickly.	33.33	40	16.67	6.67	3.33
7- When topics are spaced out, I pay greater attention.	30	40	23.33	6.67	0
8- When lessons are spaced out, it inspires me more.	16.67	50	16.67	3.33	13.33
9- When learning topics are spaced out, I get less bored.	33.33	6.67	43.33	16.67	0
10- I'm pleased that spaced practice has made vocabulary study enjoyable for me.	40	10	30	20	0
11- Spaced-out classes make vocabulary learning more enjoyable.	40	33.33	13.33	13.33	0
12- I appreciate repeating actions over and over again.	16.67	60	16.67	6.67	0
13- I prefer to acquire words by spaced practice from now on.	66.67	13.33	16.67	3.33	0
14- In general, I agree that lessons should be spaced out.	50	36.67	3.33	0	0

Note. 1 = Strongly Agree; 2 = Agree; 3 = No Idea; 4 = Disagree; 5 = Strongly Disagree.

As illustrated in Table 10, the distribution of responses indicates a predominantly positive perception of spaced vocabulary instruction. A substantial proportion of participants selected “Strongly Agree” or “Agree” for items related to improved recall (Item 1), enhanced retention (Item 2), faster retrieval during assessments (Item 4), and noticeable vocabulary development (Item 5). Furthermore, the majority of learners expressed a preference for continuing to use spaced practice in future vocabulary learning (Item 14), reflecting a high level of acceptance of the instructional approach.

To determine whether these positive perceptions were statistically significant, one-sample t-tests were conducted to compare the mean score of each questionnaire item against the neutral midpoint of the scale (M = 3). The results are presented in Table 11.

Table 11: One-Sample t-Test Results for Questionnaire Items (Test Value = 3)

Item	Mean	SD	T	Df	Sig. (2-tailed)	Mean Difference
1	1.70	0.95	-7.49	29	.001	-1.30
2	1.53	0.73	-11.03	29	.001	-1.47
3	1.60	0.86	-8.91	29	.001	-1.40

Item	Mean	SD	T	Df	Sig. (2-tailed)	Mean Difference
4	1.83	0.95	-6.74	29	.001	-1.17
5	1.97	0.93	-6.07	29	.001	-1.03
6	2.07	1.01	-5.04	29	.001	-0.93
7	2.07	0.91	-5.60	29	.001	-0.93
8	2.47	1.17	-2.48	29	.020	-0.53
9	2.43	1.10	-2.83	29	.008	-0.57
10	2.30	1.18	-3.25	29	.003	-0.70
11	2.00	1.05	-5.22	29	.001	-1.00
12	2.13	0.78	-6.10	29	.001	-0.87
13	1.57	0.86	-9.11	29	.001	-1.43
14	1.53	0.57	-14.12	29	.001	-1.47

Note. Mean scores below 3 indicate agreement (positive perception). Mean Difference =Item Mean − 3.

The results of the one-sample t-tests confirmed that the mean scores of all 14 questionnaire items were significantly lower than the neutral midpoint ($p < .05$), indicating statistically significant positive attitudes toward spaced repetition across all dimensions assessed. The strongest agreement was observed for Items 2 and 14 (M = 1.53), reflecting learners' strong beliefs that spaced learning enhances knowledge retention and their overall endorsement of spaced instruction. Items 3 (M = 1.60) and 13 (M = 1.57) also yielded notably low means, indicating that learners perceived improved recall speed and expressed a clear preference for adopting spaced practice in the future. While all items reached statistical significance, Items 8 (M = 2.47, p = .020) and 9 (M = 2.43, p = .008) had means closer to the midpoint compared to other items, suggesting that although learners held positive views toward the motivational and boredom-reducing effects of spacing, these perceptions were relatively more moderate. This may indicate that while the cognitive benefits of spaced repetition were strongly perceived, its affective impact on sustained interest varied among learners.

Overall, the findings demonstrate that learners held favorable cognitive and attitudinal perceptions of digitally scheduled spaced vocabulary learning. When considered alongside the statistically significant performance gains observed in the experimental group, these results provide converging evidence for the effectiveness of the intervention.

RQ Three: Learners' Attitudes toward Using Quizlet Digital Flashcards with Spaced Intervals

To address the third research question—what are the ESP learners' attitudes toward using Quizlet digital flashcards with specific intervals for learning technical vocabulary—semi-structured online interviews were conducted with 10 participants from the experimental group following the intervention. The interviews explored learners' experiences through open-ended questions focusing on key areas such as motivation, engagement, perceived learning outcomes, and the overall experience of using scheduled intervals. All interviews were audio-recorded, transcribed verbatim, and subjected to thematic content analysis. The analysis resulted in the identification of four recurrent themes

reflecting learners' experiences with the intervention. These themes and their frequency of occurrence are presented in Tables 12 and 13.

Table 12: Interview Themes Identified Through Content Analysis

Interview themes	Respondents
Motivation	5
Improved Engagement	4
Creating a Competing Environment	3
Improving the capacity for vocabulary learning	4

Table 13: Representative Quotations for Each Theme

Theme	Participant	Representative Quotation
Motivation	P2	"I felt motivated to keep going because I knew the next review session was already planned. It pushed me to prepare better each time."
	P5	"The intervals gave me something to look forward to. I wanted to see if I could remember more words than the last time."
	P7	"Honestly, before this method, I used to just memorize words the night before the exam. But with spacing, I felt more driven to study regularly because I didn't want to fall behind."
Improved Engagement	P1	"Every time I reviewed the flashcards, I noticed I was paying more attention to the details of each word—like spelling and how it's used in a sentence—because I had seen it before and could focus on deeper things."
	P4	"The different activities on Quizlet—matching, writing, listening—kept me involved. I didn't just passively look at words; I actually worked with them each session."
	P9	"I found myself spending more time on the flashcards than I expected. The spaced schedule made each session feel manageable, so I didn't skip any."
Creating a Competitive Environment	P3	"When we had timed activities, it felt like a challenge. I kept trying to beat my own score, and that made me focus more."
	P6	"I liked that there was time pressure. It made me take the practice seriously, almost like a game. I competed with myself to get faster."
	P10	"Seeing my progress over the sessions was motivating. I wanted to do better each round, and the time limits made it more exciting."
Improving the Capacity for Vocabulary Learning	P1	"After a few weeks, I realized I could recall architectural terms without struggling. The repeated exposure at different times really helped the words stick in my memory."
	P4	At first, the technical words seemed impossible to remember. But after reviewing them several times with gaps in between, they became familiar. It was like my brain had more room for new words."
	P8	"I noticed that I could handle more vocabulary items by the end. The spacing made it less overwhelming—I didn't feel like I was cramming everything at once."
	P5	"The intervals helped me process each word better. By the third or fourth review, I didn't even need to think hard—the meaning just came to me naturally."

Theme 1. Motivation: Motivation emerged as the most frequently mentioned theme, reported by five out of ten participants. Learners described the scheduled intervals as stimulating and energizing, explaining that the structured timing of review sessions increased their willingness to remain involved in vocabulary practice. As P2 explained, knowing that review sessions were pre-planned created a sense of purpose and encouraged more consistent preparation. P7 highlighted a shift from last-minute memorization habits toward regular, distributed study, attributing this change to the accountability created by the spaced schedule. Participants generally conveyed that the predictability and structure of the intervals transformed vocabulary study from a burdensome task into an achievable routine.

Theme 2. Improved Engagement: Improved engagement was another prominent theme, mentioned by four participants. Learners indicated that the spaced format encouraged consistent interaction with vocabulary items and supported deeper processing of word meanings, spelling, and contextual usage. P1 noted that repeated encounters with the same items allowed attention to shift from surface-level recognition to more detailed processing of usage and form. P4 emphasized the role of Quizlet's varied activity modes—such as matching, writing, and listening exercises—in sustaining active involvement across sessions. P9 remarked that because each spaced session felt manageable in length, the likelihood of skipping practice was reduced, which contributed to sustained engagement over the six weeks.

Theme 3. Creating a Competitive Environment: The theme of a competitive learning environment emerged in three interviews. Participants described the time constraints embedded in certain Quizlet activities as creating a sense of challenge, which fostered focus and persistence. Rather than perceiving the time limits as restrictive, learners viewed them as motivating elements that enhanced their involvement in the learning process. P3 and P6 both described competing against their own previous scores as a source of motivation, while P10 noted that tracking visible progress over sessions reinforced a sense of achievement and encouraged continued effort.

Theme 4. Improving the Capacity for Vocabulary Learning: Four participants reported that structured spaced repetition expanded their perceived capacity for learning technical vocabulary. P1 described a noticeable reduction in the effort required to recall architectural terminology after several spaced review cycles. P4 reported that words that initially seemed difficult gradually became familiar through repeated encounters distributed over time, reducing the sense of cognitive overload. P8 emphasized that spacing made the learning process less overwhelming by distributing the vocabulary load across manageable sessions rather than concentrating it within a single study period. P5 described a shift toward more automatic retrieval, noting that after multiple spaced reviews, meanings surfaced without deliberate effort.

Overall, the qualitative findings corroborate the quantitative questionnaire and test results. Learners not only demonstrated measurable improvement in technical vocabulary acquisition but also articulated positive cognitive and motivational experiences associated with digitally scheduled spaced practice. The convergence of performance data and thematic evidence strengthens the overall interpretation that structured spaced repetition can effectively enhance both vocabulary learning outcomes and learner engagement in ESP contexts.

Discussion

The present study examined the impact of scheduled spaced intervals implemented through Quizlet digital flashcards on ESP learners' acquisition of technical vocabulary. The findings demonstrated that although both groups improved over the six-week intervention, the experimental group—who practiced vocabulary at predetermined intervals—outperformed the control group significantly. These results provide empirical support for the superiority of spaced practice over non-scheduled or massed digital review in ESP vocabulary learning contexts.

The quantitative findings demonstrated that the experimental group achieved significantly greater vocabulary gains than the control group, as confirmed by the independent-samples t-test on gain scores, $t(58) = -5.456$, $p < .001$. The mean gain of the experimental group ($M = 5.48$) was substantially larger than that of the control group ($M = 0.16$), indicating that structured spaced intervals were the primary factor driving vocabulary improvement. This interpretation is consistent with cognitive research indicating that retrieval distributed over time strengthens consolidation processes and supports durable retention [12-24].

Beyond achievement scores, the questionnaire results revealed that learners perceived spaced digital learning as more efficient, less cognitively overwhelming, and more enjoyable. Participants reported greater autonomy, flexibility, and sustained engagement when using Quizlet with defined intervals. These affective findings are particularly significant in ESP contexts, where technical vocabulary is often perceived as demanding and demotivating. Research in mobile-assisted and technology-enhanced language learning similarly suggests that structured digital environments can increase motivation and self-regulated engagement when learning sequences are pedagogically organized [28-29].

Although the present study did not directly measure constructs from the Technology Acceptance Model (TAM) or the Theory of Planned Behavior (TPB), the results appear theoretically consistent with these frameworks. Learners' positive perceptions of structured Quizlet use suggest enhanced perceived usefulness and perceived ease of use, two central determinants of technology adoption in TAM. Moreover, the increased willingness to continue using the application may reflect strengthened behavioral intention, a key component of TPB. Therefore, while TAM and TPB were not empirically tested in this study, the findings provide indirect support for their explanatory relevance in technology-mediated ESP learning environments.

Qualitative interview data further enriched these interpretations. Participants described the spaced sessions as engaging, competitive, and cognitively manageable. Features such as repeated exposure across different activity modes (e.g., matching, listening, writing, and live games) appeared to facilitate retrieval strength and response speed. Importantly, learners emphasized that spacing reduced feelings of overload and enhanced confidence in using newly acquired architectural terminology. These perceptions correspond with the quantitative improvements observed in post-test scores.

The present findings extend the results of Lotfolahi and Salehi [19], who demonstrated the long-term advantages of spaced practice over massed learning among young EFL learners. Unlike their study, however, the current research situates spacing within a digital ESP environment and integrates affective dimensions through survey and interview data. Similarly, the results are consistent with Nakata

[18], who reported learners' positive perceptions toward spaced schedules in computer-assisted vocabulary learning. The findings also resonate with Serfaty and Serrano [20], who found that the interval between Quizlet practice sessions influenced the retention of newly learned foreign-language vocabulary.

In the present study, the combination of academic relevance, structured intervals, and interactive digital tools appears to have strengthened both retention and learner motivation. Furthermore, consistent with research highlighting the positive attitudinal impact of technology integration [30-29-32], participants expressed increased enjoyment and reduced resistance toward vocabulary learning when technology was purposefully structured.

Overall, the study demonstrates that the pedagogical value of digital flashcards does not lie merely in their technological features, but in how they are strategically integrated into instructional design. Structured spacing, rather than unsystematic repetition, appears to be the critical factor enhancing technical vocabulary acquisition in ESP contexts.

Conclusions

Aiming to determine the efficacy of spaced repetition in technical vocabulary learning, this study investigated the impact of digitally scheduled review on Iranian undergraduate ESP learners in Architecture. The findings confirm that a structured two-day interval schedule significantly enhances retention compared to unstructured digital practice, reinforcing the cognitive principle that distributed retrieval strengthens memory consolidation. These results extend existing evidence on spaced repetition to the specific domain of digitally mediated ESP instruction. Furthermore, the study highlights that learners not only achieve superior academic outcomes but also hold strongly positive perceptions of this approach, viewing it as a valuable and engaging tool. Consequently, integrating spaced repetition algorithms into ESP curricula appears to be a pedagogically sound and learner-friendly method for fostering durable vocabulary knowledge.

Beyond the primary performance metrics, the study explored learner perceptions, revealing a strong consensus on the efficacy of spaced repetition in retaining technical vocabulary. While cognitive benefits such as improved recall speed and long-term memory consolidation were universally acknowledged, affective factors like motivation and engagement displayed a nuanced pattern, varying slightly across individuals. Qualitative insights deepened this understanding by highlighting four pivotal themes: heightened motivation, sustained engagement, a competitive learning atmosphere, and expanded vocabulary capacity. Participants emphasized that the structured intervals instilled a sense of accountability, shifting their approach from superficial recognition to deep, contextual processing of architectural terminology. Moreover, the time-bound nature of the digital tasks fostered a healthy competitive spirit that maintained focus, while the distributed practice significantly alleviated cognitive load, rendering complex concepts more manageable. Ultimately, these findings suggest that integrating spaced repetition into ESP curricula not only optimizes retention but also cultivates a psychologically supportive environment that encourages persistent and meaningful learning.

Synthesizing the quantitative and qualitative evidence, this study concludes that the pedagogical efficacy of digital flashcards hinges not on their technological features, but on the

strategic integration of cognitive mechanisms like spaced retrieval. When these tools are designed around theoretical principles rather than used as ad hoc resources, they significantly enhance vocabulary retention and foster positive learner attitudes. These findings resonate with the Technology Acceptance Model and the Theory of Planned Behavior, underscoring that perceived usefulness and behavioral control are pivotal in sustaining engagement with learning technologies.

These findings offer critical implications for ESP pedagogy and curriculum design. First, technical vocabulary acquisition in specialized fields requires intentional instruction paired with structured spaced repetition, rather than relying solely on incidental learning. Second, digital platforms like Quizlet and Anki are effective for implementing these principles, provided review intervals are systematically planned by instructors rather than left to learner discretion. Third, educators should embed spaced scheduling as a core syllabus component, treating technology as an essential instructional tool rather than an optional supplement. Finally, the positive learner perceptions suggest that this approach can mitigate the affective barriers of dense terminology, thereby enhancing learner autonomy and sustaining motivation.

Several limitations warrant acknowledgment. First, the use of convenience sampling from a single institution restricts the generalizability of findings to other contexts. Second, the sample size of 60 participants, while sufficient for large effects, limits statistical power. Third, the quasi-experimental design using intact groups, despite baseline equivalence, leaves room for uncontrolled pre-existing differences. Finally, the exclusive focus on receptive vocabulary via multiple-choice items overlooks productive skills (speaking/writing), potentially underestimating the full scope of lexical acquisition. Fifth, the six-week intervention lacked a delayed post-test, leaving long-term retention effects unverified. Sixth, the control group used Quizlet without structured spacing; thus, the study isolates the spacing variable but limits conclusions regarding the broader efficacy of digital flashcards versus traditional methods. Seventh, qualitative data relied on self-reports, which may be influenced by social desirability bias. Eighth, instruction by a single instructor, while controlling for teacher variability, may constrain ecological validity if specific instructor characteristics drove the outcomes. Finally, administering the questionnaire only to the experimental group post-intervention prevented comparative analysis of perceptions between groups and pre-post attitude changes.

To address the limitations and extend findings, future research should prioritize investigating the transfer of spaced repetition benefits to productive vocabulary skills, such as speaking and writing. Longitudinal designs incorporating delayed post-tests at intervals of several months are essential to assess the durability of these learning effects. To enhance generalizability, subsequent studies ought to employ larger, multi-institutional samples across diverse ESP disciplines, including engineering and medicine, to determine if disciplinary context moderates retention. Furthermore, researchers should systematically compare various digital flashcard platforms and spacing algorithms to identify optimal configurations and explore how spaced repetition interacts with broader pedagogical frameworks like task-based or communicative language teaching. Finally, methodological rigor can be strengthened by administering pre-test questionnaires to both groups, adapting post-tests to capture the control group's experiences, and supplementing self-reports

with objective engagement metrics, such as platform usage analytics.

Authors' Contribution

All authors contributed equally to this work. Each author was actively involved in the conception and design of the study, data collection, analysis, and interpretation of the results. They collaboratively drafted, reviewed, and revised the manuscript to ensure intellectual accuracy and clarity. All authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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Conflict of Interest

There was no conflict of interest among the authors.

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Appendix

Semi- Structured Interview Questions: The following questions were used to guide the interviews with participants from the experimental group:

1- How did the use of Quizlet with scheduled intervals affect your **motivation** to learn the technical vocabulary?

2- Can you describe your level of **engagement** with the tool? Did the specific timing make you more or less involved in the learning process?

3- Did you experience any sense of **challenge or competition** due to the time constraints? How did this influence your focus?

4- In your opinion, how did this spaced repetition method impact your **capacity to learn and retain** the new words compared to other methods?

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