



AI-Powered Mobile Applications for Adaptive Vocabulary Learning: A State-of-the-Art Review on Supporting Learner Autonomy

Hassan Chelongar

*PhD Student in TEFL, Department of
English, Na.C.,*

Islamic Azad University,

Najafabad, Iran

h.chelongar@iau.ac.ir

Hadi Salehi (Corresponding Author)

*Assistant Professor, Department of
English, Na.C.,*

Islamic Azad University,

Najafabad, Iran

hadisalehi@iau.ir

Omid Tabatabaei

*Associate Professor, Department of
English, Na.C.,*

Islamic Azad University,

Najafabad, Iran

tabatabaeiomid@iau.ir

Abstract—Recent advances in artificial intelligence have reshaped mobile language learning environments, particularly in the area of vocabulary acquisition. AI based mobile applications increasingly employ adaptive personalization, learning analytics, and intelligent feedback to support individualized vocabulary practice. At the same time, learner autonomy has gained prominence as a key pedagogical objective in technology enhanced language learning, emphasizing learners' capacity to plan, monitor, and regulate their own learning. This paper presents a state-of-the-art review of research on AI based mobile applications for vocabulary learning, with a specific focus on how intelligent system features relate to the development of learner autonomy. Drawing on recent studies from intelligent educational systems, mobile assisted language learning, and applied linguistics, the review synthesizes current design approaches, adaptive mechanisms, and pedagogical assumptions underlying AI supported vocabulary instruction. The analysis highlights both the affordances of AI driven mobile applications and persistent conceptual, methodological, and design limitations, particularly regarding the operationalization and evaluation of learner autonomy. The paper concludes by outlining implications for intelligent system design and language learning practice, emphasizing the need for transparent, autonomy supportive AI driven mobile applications grounded in sound vocabulary learning principles.

Keywords—*AI-based mobile applications, adaptive learning, vocabulary acquisition, learner autonomy, mobile-assisted language learning, intelligent educational systems*

I. INTRODUCTION

The integration of artificial intelligence (AI) into educational technology has rapidly reshaped language learning environments, particularly through AI-based mobile applications that offer adaptive and personalized learning experiences [1], [2]. These applications increasingly incorporate intelligent feedback, real-time customization, and performance tracking to support vocabulary acquisition more effectively than traditional, non-adaptive methods. Empirical

evidence suggests that mobile language apps can enhance retention and learner engagement through dynamic practice features and algorithm-driven pacing [3]. AI-powered applications are not limited to vocabulary alone; research in intelligent language systems has demonstrated broader impacts on language learning outcomes, including speaking proficiency, grammar usage, and interactive learning experiences when compared with control groups using traditional methods [4]. In addition to improving performance outcomes, AI-enabled learning environments have been linked to increased opportunities for self-regulated and autonomous learning. Learners using mobile devices with self-regulated learning (SRL) support mechanisms have shown stronger vocabulary gains compared to traditional learning conditions, highlighting a positive relationship between mobile SRL strategies and language outcomes [5], [6]. Furthermore, the development of learner autonomy—the capacity to plan, monitor, and adjust one's learning strategies independently—has been shown to correlate with the integration of intelligent features that promote learner choice and metacognitive engagement [7].

Despite these advances, research in this domain remains dispersed across applied linguistics, educational technology, and intelligent systems design, often with varying theoretical frameworks and methodological approaches. Past reviews indicate generally positive trends for mobile and AI-enhanced learning but emphasize the need for focused synthesis on how AI-based mobile applications support vocabulary acquisition and learner autonomy in tandem [7], [8]. This paper synthesizes contemporary findings, identifies prevailing design and pedagogical trends, and highlights gaps that warrant future theoretical and empirical inquiry.

II. BACKGROUND AND CONCEPTUAL FOUNDATIONS

AI-based mobile applications employ adaptive algorithms, natural language processing, and learning analytics to deliver personalized instruction aligned with learners' proficiency levels, learning pace, and retention patterns [1], [2]. These applications dynamically adjust content and exercises based on individual performance, providing targeted practice and feedback that enhance both engagement and long-term retention [3], [4]. By offering such adaptive and personalized experiences, AI-driven tools support more effective vocabulary acquisition compared to traditional instructional methods.

A key consideration in AI-assisted language learning is the development of learner autonomy. Autonomous learners can set goals, monitor progress, and regulate their study behaviors independently, which is critical for sustained vocabulary growth [5], [6]. Mobile applications that provide self-paced learning, immediate feedback, and adaptive drills facilitate the cultivation of these skills, supporting both motivation and language development [7], [8].

Research across educational technology, applied linguistics, and intelligent systems demonstrates that mobile vocabulary tools benefit from multimedia content, gamification, and spaced repetition strategies, all of which contribute to more robust vocabulary acquisition [9], [2]. In addition, AI-powered analytics allow instructors and learners to identify knowledge gaps and track progress over time, further reinforcing autonomous learning and targeted intervention. Integration of adaptive personalization, pedagogical functionality, and learner autonomy provide a foundational framework for implementation of vocabulary teaching and learning. Understanding these principles is essential for interpreting current research trends and identifying areas for future investigation [2], [3].

III. STATE-OF-THE-ART DEVELOPMENTS IN AI-BASED MOBILE APPLICATIONS FOR VOCABULARY LEARNING

Recent research reflects a growing interest in how AI-enhanced mobile applications can support vocabulary learning and related language skills. One foundational area of research examines mobile-assisted vocabulary learning (MAVL). A comprehensive bibliometric review of MAVL research found that the number of publications in this domain has increased substantially, with most studies focusing on learner vocabulary achievement, affective behaviors, and attitudes toward mobile learning tools [12]. This review highlights that while mobile technologies facilitate independent learning due to their anytime-anywhere nature, there remains limited diversity in topics studied and a lack of international collaboration among researchers, suggesting opportunities for broader, interdisciplinary work. Comparative studies provide additional empirical support. For instance, research comparing the use of mobile applications with traditional instructional methods demonstrated that learners using mobile apps outperformed control groups on vocabulary tests, indicating that mobile technologies can enhance both retention and motivation [14]. The introduction of AI capabilities marks a significant advancement over earlier MAVL systems. AI has been integrated into mobile language learning applications to provide real-time, personalized support and to enhance self-efficacy. For example, a recent experimental study involving Duolingo's generative AI

features reported that learners experienced increased self-efficacy for language use after extended engagement with AI-supported practice activities in a mobile app environment [2].

Beyond vocabulary, broader applications of AI-powered mobile tools demonstrate their potential to enhance language skills through tailored feedback and adaptive sequencing. A mixed-methods study comparing AI-enhanced mobile learning with conventional social networking app use found significant improvements in speaking outcomes, although vocabulary and grammar sub-skills showed non-significant upward trends, indicating variability in how AI tools impact different aspects of language learning [15]. These findings underline the importance of design specificity in AI systems if vocabulary acquisition is to be directly targeted rather than incidental. In addition to adaptive personalization, emerging research explores extended reality (XR) and other immersive technologies that carry implications for vocabulary learning. A recent systematic review on the integration of AI and extended reality in language education highlights the potential for multimodal, context-rich learning environments that can support vocabulary practice in realistic settings [16]. While these studies illustrate technological progress, several challenges remain. Many mobile applications still rely on generic personalization or rule-based adaptive pathways rather than truly intelligent learning analytics, and ethical considerations such as algorithmic bias and equitable access have been highlighted in recent reviews [17]. Furthermore, the fragmentation of research across different fields suggests a need for clearer frameworks that integrate AI algorithm design, language pedagogy, and learner autonomy theory.

IV. THEMATIC SYNTHESIS: LEARNER AUTONOMY AND AI MECHANISMS

A central theme in contemporary research is the role of AI-driven personalization, where algorithms continuously analyze learner performance data to adapt content, pacing, and sequencing in real time [16]. These adaptive adjustments help maintain an optimal cognitive challenge for the learner, enhancing both engagement and retention. Machine learning techniques applied to item selection and spacing have been shown empirically to improve vocabulary outcomes when compared to static practice schedules [3]. Such personalization ensures that practice is responsive to individual needs rather than uniform across learners.

Another mechanism involves interactive feedback, often enabled by natural language processing (NLP) and conversational agents. AI-powered chatbots and dialogue systems can simulate communicative contexts and provide immediate corrections or examples, reinforcing vocabulary in context rather than in isolation [10], [11]. Studies indicate that such feedback promotes deeper processing of lexical items and supports learners' metacognitive engagement with errors and revisions. When learners can interact with an AI system that responds to their input, motivation and language confidence tend to increase [2].

Mobile applications uniquely harness the ubiquitous and flexible nature of handheld devices to embed learning into daily routines. Features such as spaced repetition, multimedia support, and microlearning exercises have been linked to higher rates of vocabulary retention and learner engagement [12]. Furthermore, gamified elements like adaptive challenges and progress badges are associated with increased time-on-task behaviors, which are important precursors to autonomous engagement [14]. When adaptive gamification aligns with

pedagogical goals, learners are more likely to return to practice independently.

AI mechanisms also intersect with learner autonomy and (SRL) by enabling learners to set goals, monitor performance, and adjust strategies without constant teacher intervention. Research in language learning contexts has found that AI-mediated environments that provide dashboards, progress charts, and personalized recommendations support learners' planning and monitoring processes [5]. These support structures encourage learners to take ownership of practice decisions, a key dimension of autonomy.

Moreover, studies examining the relationship between autonomous strategy use and AI-supported vocabulary practice suggest that learners who engage in self-regulated behaviors—such as systematic revision or strategy selection—tend to achieve higher vocabulary gains than those relying on guided instruction alone [6]. This evidence indicates that AI features can act as both a scaffold and a catalyst for autonomous regulation, strengthening the learner's ability to self-direct. Together, these mechanisms show that AI-based mobile applications do more than present vocabulary; they create dynamic learning ecosystems where personalization, feedback, engagement, and autonomy are interwoven. For example, adaptive task sequencing informed by learning analytics can trigger personalized feedback that encourages learners to reflect on errors, thereby supporting self-regulated strategies. Similarly, mobile affordances allow learners to practice in varied contexts, reinforcing autonomy through flexibility in time and place.

This synthesis underscores that the pedagogical affordances of AI are not solely technological features but are deeply connected to how learners interact with tasks, make decisions, and sustain engagement over time. Understanding these interconnections is essential for both researchers and designers who aim to create vocabulary learning tools that are not only efficient but also learner-centered and autonomy-supportive.

V. CHALLENGES, LIMITATIONS, AND RESEARCH GAPS IN AI-BASED MOBILE VOCABULARY LEARNING

Despite the growing body of research demonstrating positive outcomes for AI-based mobile applications in vocabulary learning, the literature reveals a number of unresolved conceptual, methodological, and design-related challenges that constrain both interpretation and application of findings. One prominent limitation concerns the treatment of learner autonomy as a construct. Although autonomy is frequently referenced as a benefit of mobile and AI-supported learning environments, it is often conceptualized implicitly rather than operationalized through established theoretical models of autonomy or self-regulated learning [4], [12], [7]. In many studies, autonomy is inferred from increased engagement, learner satisfaction, or flexible access rather than directly examined through learners' abilities to plan, monitor, and evaluate their vocabulary learning strategies, a pattern also noted in recent systematic reviews of AI-supported self-regulated learning [7].

A related issue is the narrow focus on vocabulary learning outcomes. Empirical studies of AI-based mobile applications frequently prioritize short-term gains measured through

recognition-based tests or immediate post-intervention assessments [14], [3]. While such measures are convenient and compatible with automated assessment systems, they offer limited insight into deeper dimensions of lexical competence, including productive use, contextualized understanding, and long-term retention. Research in applied linguistics has long emphasized that vocabulary knowledge is multidimensional, yet these dimensions remain underrepresented in evaluations of AI-driven mobile learning tools [9], [10]. As a result, claims regarding the effectiveness of AI-supported vocabulary learning may overestimate short-term performance while underestimating challenges related to sustained, autonomous vocabulary development.

Methodological limitations further complicate the research landscape. Many studies employ relatively short intervention periods and small, context-specific samples, often drawn from single institutions or homogeneous learner populations [12], [6]. Such designs limit the generalizability of findings and provide little evidence regarding the long-term development of learner autonomy. Moreover, learner autonomy and self-regulation are frequently assessed through self-report instruments, which, while valuable, are susceptible to bias and may not accurately reflect learners' actual strategic behaviors [5]. Although learning analytics and log data are increasingly incorporated into AI-based systems, these data are rarely triangulated with qualitative methods such as learner interviews or reflective journals, reducing the depth of insight into how learners interact with adaptive features over time.

From a technological standpoint, there remains a significant gap between the theoretical potential of artificial intelligence and its practical implementation in many mobile vocabulary learning applications. While studies often describe systems as adaptive or AI-driven, personalization is frequently achieved through predefined rules or basic performance thresholds rather than advanced machine learning models capable of modeling learner strategies or metacognitive states [17], [16]. This distinction is critical, as rule-based adaptation may optimize task sequencing without meaningfully supporting learner autonomy. Furthermore, the lack of transparency and explainability in adaptive systems limits learners' understanding of why particular vocabulary items or activities are recommended, thereby restricting opportunities for reflection and informed self-regulation [8], [11].

The balance between system control and learner agency represents another underexplored challenge. While adaptive algorithms are designed to optimize learning efficiency, excessive system-driven decision-making may inadvertently reduce learners' sense of ownership over the learning process. Few empirical studies systematically investigate how varying levels of learner control over content selection, pacing, or feedback influence autonomy development in AI-supported mobile environments [5], [4]. This gap suggests a need for design approaches that position AI as a scaffold for developing independent regulation rather than as a replacement for learner decision-making.

Practical concerns further complicate the deployment of AI-based mobile vocabulary learning systems. The extensive collection of learner data raises issues related to privacy,

consent, and data security, particularly in mobile contexts where learning often occurs in informal and personal spaces [17]. In addition, algorithmic bias and unequal access to advanced AI-powered applications risk exacerbating existing educational inequalities, a concern increasingly highlighted in broader discussions of AI in education but rarely addressed directly in vocabulary learning research. The growing emphasis on fully automated systems may also marginalize the role of teachers, despite evidence that pedagogical guidance remains essential for supporting reflective and strategic language learning [9], [4].

The interdisciplinary nature of this research area has resulted in a fragmented body of literature. Studies originating from applied linguistics, mobile-assisted language learning, and intelligent systems design often adopt different theoretical assumptions and evaluation criteria, making it difficult to synthesize findings into coherent design principles [2], [10]. This fragmentation limits cumulative knowledge building and underscores the need for integrative frameworks that connect AI mechanisms, vocabulary learning theory, and learner autonomy research.

VI. IMPLICATIONS FOR INTELLIGENT SYSTEM DESIGN AND LANGUAGE LEARNING PRACTICE

The findings of this state-of-the-art review highlight the need to position learner autonomy as a central design principle in AI-based mobile applications for vocabulary learning rather than as a secondary outcome of technological innovation. While adaptive algorithms and learning analytics enable personalized practice, their educational value depends on how transparently and pedagogically these mechanisms are implemented. Research in mobile-assisted language learning and self-regulated learning indicates that autonomy is best supported when learners can interpret and act upon system-generated feedback, rather than passively follow automated recommendations [5], [4].

From a system design perspective, AI-driven mobile applications should move toward explainable and learner-aware adaptation. Making personalization processes visible—for example, by clarifying why specific vocabulary items are selected or how repetition schedules are determined—can promote metacognitive awareness and reflective learning behaviors [8], [11]. Such transparency aligns with broader developments in intelligent systems research emphasizing accountability and user trust, particularly in data-intensive learning environments [17].

Balancing adaptive automation with learner control represents another critical implication. While AI systems can optimize task sequencing and pacing, excessive system-driven decision-making may limit learners' sense of ownership. Studies suggest that autonomy is strengthened when learners can set goals, prioritize vocabulary items, and adjust pacing in line with personal needs and contexts [6], [5]. Designing mobile applications that allow flexible levels of guidance may therefore better support the gradual development of independent regulation.

Pedagogically, AI-based vocabulary learning tools should be grounded in established principles of vocabulary acquisition, including lexical depth, contextualized use, and

meaningful repetition. Although intelligent systems excel at delivering individualized practice, they must incorporate tasks that encourage productive vocabulary use and semantic processing to ensure durable learning outcomes [9], [10]. Mobile affordances such as multimedia input and microlearning are most effective when guided by pedagogical intent rather than technological novelty.

The role of teachers remains essential in AI-enhanced mobile learning ecosystems. Rather than replacing instruction, AI-based applications should complement classroom practices by extending opportunities for individualized and autonomous practice. Research emphasizes that teachers play a key role in helping learners interpret feedback, reflect on strategies, and integrate mobile learning into broader curricular goals [4], [12]. Ethical considerations, including data privacy, transparency, and equitable access, must also inform both design and implementation to ensure that AI-supported mobile learning environments genuinely support learner autonomy [17].

VII. CONCLUSION

This review identified significant conceptual, methodological, and design-related challenges that limit current research and practice. These limitations suggest that technological sophistication alone is insufficient to guarantee meaningful learning outcomes. The findings underscore the need for greater integration between AI system design, language learning theory, and autonomy-oriented pedagogy. AI-based mobile applications are most likely to realize their potential when they function as transparent, supportive tools that scaffold learners' ability to regulate their own vocabulary learning. By emphasizing learner agency alongside intelligent adaptation, future developments can contribute to improved vocabulary acquisition and the cultivation of lifelong, autonomous language learners.

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