Mobile-Assisted Language Learning (MALL) with Google Forms: Enhancing ESL Speaking Proficiency in Engineering Students

Amir[1], Sohaib Alam[2,*], Anam Shams[3], Bahia Khalifa Ibrahim Mohammed[2], Mohammad Usama[4], and Sameena Banu[2]

[1]Department of Humanities, Galgotias College of Engineering and Technology, Greater Noida, India
[2]Department of English Language and Literature, College of Sciences and Humanities, Prince Sattam Bin Abdulaziz University, AlKharj, Kingdom of Saudi Arabia
[3]College of Arts, University of Hafar Al Batin, Hafar Al Batin, Saudi Arabia
[4]School of Business, Galgotias University, Greater Noida, India
Email: amirkhan@galgotiacollege.edu (A.); s.alam@psau.edu.sa (S.A.); anam@uhb.edu.sa (A.S.); b.mohammed@psau.edu.sa (B.K.I.M.); mohammad.usama@galgotiasuniversity.edu.in (M.U.); s.banu@psau.edu.sa (S.B.)
*Corresponding author
Manuscript received January 16, 2025; revised March 24, 2025, accepted May 26, 2025; published October 14, 2025

***Abstract*—Mobile Assisted Language Learning (MALL) technology is being incorporated in various ways in language classrooms; however, limited research has examined the effects of using Google Forms on mobile devices to enhance the speaking proficiency of engineering students. Therefore, this study implemented Google Forms on mobile devices, incorporating listening and reading comprehension exercises to enhance English proficiency. An experimental design study was utilized with 165 first-year students, forming two groups: an experimental group (*N* = 86) and a control group (*N* = 79). The experimental group improved their English-speaking proficiency through listening and reading comprehension exercises accessed via Google Forms on mobile devices in the English for Second Language (ESL) classroom. While the experimental group engaged with comprehension exercises and instructor-led discussions via Google Forms, the control group practiced speaking directly with the instructor. The results of the study showed that the experimental group using mobile Google Forms outperformed the control group in speaking proficiency. Findings suggest that integrating Google Forms on mobile devices can positively impact ESL speaking proficiency, highlighting the potential of mobile-assisted learning in language education.**

***Keywords*—mobile technology, English speaking proficiency, google form, engineering students, language learning**

I. Introduction

English has solidified its role as the global lingua franca, essential for facilitating communication across domains including business, science, technology, and academia, demonstrating its widespread adoption by multinational corporations and its indispensable role in the internet, scientific communication, and international diplomacy [1–3]. This ubiquity underscores the importance of English proficiency, particularly for engineers who frequently work in international or multicultural contexts where English leads as the communication medium [4]. For engineering students, the mastery of English excels academic requirements and emerges as a critical professional skill that significantly enhances employability, ensures effective communication in future careers, and provides access to an extensive range of global resources and technologies predominantly documented in English [5]. Proficiency in English, especially speaking skills, is crucial for engineers to articulate their ideas clearly and to actively participate in professional discussions and presentations, which are vital for career advancement [6]. However, the development of effective speaking skills is heavily dependent on a strong foundation in listening and reading comprehension. These foundational skills furnish learners with critical linguistic inputs such as vocabulary, grammar, idioms, and phrases and expose them to models of fluent speech, which are essential for improving pronunciation, accuracy, and fluency [7–11]. Without a robust base in listening and reading, engineering students may find it challenging to develop their speaking skills adequately, as the lack of comprehensive language exposure can impede their ability to communicate effectively in real-world scenarios [12–14].

The study aims to explore new ways to enhance English language skills among engineering students, recognizing the essential role of foundational language abilities. Specifically, the study examines how mobile technology, particularly through the use of Google Forms, can facilitate the delivery of listening and reading comprehension exercises. These activities are designed to enhance speaking proficiency, thereby addressing a crucial component of language learning. The main hypothesis of the study posits that mobile-assisted language learning tools may offer a flexible, accessible, and engaging alternative to traditional learning environments. These tools are thought to provide the dynamic and interactive settings necessary for improving English proficiency in an English classroom context. The objective of the study is to evaluate the effectiveness of these mobile learning tools in supporting language learning and to compare their efficacy with that of conventional classroom-based instruction that does not utilize technological aids. This research aligns with broader educational initiatives that emphasize the integration of technology to foster autonomous learning and enhance educational outcomes.

This study aligns with broader educational trends that emphasize learner autonomy and technological integration in curriculum delivery. The implications of this study could inform future pedagogical strategies, highlighting the shift towards mobile technology-driven language learning and its potential impact on improving language skills in academic and professional contexts.

doi: 10.18178/ijiet.2025.15.10.2409

II. Literature Review

A. Theoretical Framework

The Constructivist Learning Theory, developed by Jean Piaget and expanded by Lev Vygotsky, posits that learning is an active process where learners build new knowledge based on existing knowledge through interaction with their environment [15, 16]. This approach emphasizes creating learning experiences that encourage learners to explore, question, and discover, with educators facilitating rather than directing the learning process. For example, in a language classroom, this might involve collaborative projects where students use the target language in practical, real-world tasks, thereby integrating direct application of linguistic skills in a meaningful context [17–20]. Additionally, the theory underscores the importance of reflective practice, where learners assess their strategies and outcomes, fostering deeper learning and self-regulation. Applying Constructivist Learning Theory thus helps create a dynamic educational environment that supports active engagement, practical application, collaborative learning, and reflective practice, making it highly effective for fostering durable and transferable knowledge [21, 22].

B. Speaking Skills of Engineering Students

English is crucial for engineering students as it is the lingua franca of the global engineering community, facilitating collaboration and access to technical literature [1, 23]. Speaking skills within this framework are particularly important as they enable clear and effective communication, critical for presentations, negotiations, and teamwork in a professional setting [24]. Fluency, accuracy, and pronunciation are essential components of speaking skills that directly influence comprehensibility and interpersonal communication [25, 26].

However, despite this recognized importance, there is limited critical evaluation of how speaking skills are practically nurtured within engineering curricula. Existing studies often emphasize general communicative competence without detailing the pedagogical methods effective for discipline-specific needs. Effective communication is paramount for engineering students as it impacts their ability to succeed in both academic and professional settings, facilitating better understanding, problem-solving capabilities, and innovation [27]. Enhancing these skills through integrated listening and reading tasks can provide contextual learning opportunities that mimic real-world engineering scenarios, promoting a deeper understanding and practical application of technical and communicative skills [28].

C. Google Form in Teaching and Learning Process

Google Forms has become an essential tool in the teaching and learning process, offering a versatile platform for online assessments, data collection, and engagement. Its user-friendly interface allows educators to design quizzes, surveys, and assignments with features like instant feedback, multiple question types, and automated grading, significantly improving efficiency and accuracy while reducing human error [29–31]. Beyond assessment, it enhances student engagement through interactive elements, fostering participation and bridging the gap between traditional and digital educational methods [32–34].

Nonetheless, many studies provide surface-level evaluations of these benefits, lacking deeper analysis of how such tools transform long-term pedagogical practices or influence different learner types. Its adoption also supports sustainable practices by reducing paper usage, aligning with environmentally conscious approaches [35, 36]. Additionally, its integration with tools like Google Sheets facilitates seamless data analysis and real-time performance tracking, enabling educators to tailor interventions based on empirical evidence [34, 35, 37]. The tool is inclusive, accessible on various devices such as smartphones, tablets, and computers, making it particularly valuable for diverse learning needs and remote education [38]. During crises like the COVID-19 pandemic, Google Forms ensured continuity in education, demonstrating adaptability to remote learning scenarios [38].

Despite its wide utility, the literature lacks comparative studies that critically contrast Google Forms with other platforms to identify contextual appropriateness and learner-specific outcomes. These features position Google Forms as an indispensable resource for modern educational practices.

D. Impact of Google Form Improving English Language Proficiency

Google Forms has been extensively acknowledged as a versatile and effective tool in educational contexts, offering a range of features to enhance teaching, learning, and assessment. Elbasyouny *et al.* [39] described Google Forms as a powerful formative assessment platform that allows educators to create quizzes, surveys, and questionnaires tailored to curriculum objectives while providing instant feedback and detailed analytics. Its real-time feedback capability, as emphasized by Dhawan [40], made it invaluable for adaptive learning by enabling teachers to adjust their strategies based on student performance data. Azhar and Iqbal [41] highlighted its efficiency in organizing and analyzing large volumes of data, streamlining the assessment process. The tool's accessibility, clean interface, and support for diverse question formats, as noted by Hocutt *et al.* [42], made it particularly user-friendly for both educators and students. Additionally, Jazil *et al.* [34] emphasized its suitability for grammar assessments, enabling educators to gain insights into specific learning areas and tailor their instructional approaches accordingly. Oktay [43] further underline its support for multimedia integration, such as embedding videos and audio files, which adds interactivity to assessments and engages learners more effectively. Gurevych *et al.* [44] provides a framework for analyzing educational data obtained through tools like Google Forms, offering methodologies to identify and address errors in student responses systematically.

Yet, while these studies underscore Google Forms' practicality, few of them interrogate the depth of its impact on different dimensions of language learning, particularly speaking skills. Moreover, many focus on grammar and vocabulary, overlooking oral fluency, pronunciation, and real-time interaction, which are central to communicative competence.

The studies by Kita [32], Wibowo and Rahmah [33], Jazil *et al.* [34], Irawansyah [35], and Alenezi [38] collectively highlighted the evolving landscape of educational

assessments facilitated by digital tools. Irawansyah's [35] research identified common morphological errors in student translations from Indonesian to English, advocating the use of Google Forms alongside bilingual dictionaries and morphology guides to enhance translation accuracy. Alenezi's [38] study provided insights into how English teachers in Saudi Arabia navigate online and alternative assessments, preferring traditional methods adapted to digital platforms like Blackboard, despite noting challenges such as cheating and a need for better digital literacy. Wibowo and Rahmah [33] demonstrated that Google Forms, aided by WhatsApp, effectively supported English learning evaluations in Jakarta, significantly improving student engagement and performance despite technological barriers. Meanwhile, Kita's [32] work showed how Google Forms quizzes on smartphones could boost Japanese university students' motivation and language skills by providing real-time feedback, though it called for further research into long-term motivational impacts. Together, these studies underscore the potential of digital tools to enhance educational outcomes, while also emphasizing the need for improvements in technology integration and user training to overcome existing challenges.

Together, these studies provide useful context but reveal a narrow scope of inquiry focused largely on assessment utility and not on communicative development. Further research is needed to critically analyze how different features of Google Forms may foster or hinder specific language domains.

Gurevych *et al.* [44] highlighted the versatility of Google Forms in educational settings, emphasizing its effectiveness for creating online assessments, surveys, and quizzes through features such as multiple-choice and essay formats, as well as instant feedback. Haddad and Kalaani [45] support these findings, noting its utility as a formative assessment tool that provides real-time feedback and allows educators to monitor student progress effectively. However, Wibowo and Rahmah [33] noted that Google Forms lacks gamified features like those in Quizizz, which may limit its appeal in contexts requiring high engagement, particularly for younger learners.

This raises concerns about learner motivation, especially among students with shorter attention spans, suggesting the need to balance efficiency with engagement through innovative design. Despite this limitation, the study concludes that Google Forms remains a practical, efficient, and environmentally friendly tool for digital assessments, with its optimal application depending on specific educational contexts and user preferences.

The studies conducted by Alarfaj [46], Djenno *et al.* [47], Rizal *et al.* [30]; Sandhya *et al.* [48] demonstrated the diverse impacts and perceptions of using Google Forms as a digital assessment tool in educational settings. Sandhya *et al.* [48] studied on university students showed that those assessed with Google Forms significantly outperformed peers assessed with traditional methods, evidencing Google Forms' effectiveness in enhancing English grammar mastery and student engagement. Alarfaj [46] further explored this tool's use in Saudi Arabian secondary schools, finding that both teachers and students appreciated the immediate feedback and flexibility of Google Forms, although concerns about cheating and technical challenges suggested a need for better training and digital literacy. Rizal *et al.* [30] studied at SMP Negeri Muara Teweh reported that while 80% of teachers found Google Forms facilitated assessments, a significant gap existed in its practical application, with only 25% actively using it, underscoring the need for further training to leverage its full potential. Similarly, Djenno *et al.* [47] highlighted that Google Forms effectively improved vocabulary mastery among junior high students in Semarang, suggesting its suitability for online and blended learning environments.

These studies collectively affirm the tool's utility but also expose systemic barriers to adoption, particularly related to digital access and pedagogical support.

Previous research in Mobile-Assisted Language Learning (MALL) has extensively examined its impact on broad language learning outcomes, yet it has often overlooked the specialized needs of engineering students, who must master specific technical vocabulary and advanced communication skills to thrive professionally. Furthermore, the literature has predominantly utilized tools like Google Forms for assessments of reading and writing proficiency, neglecting their potential to enhance spoken English skills, which are crucial for engineering students facing real-world challenges that require precise and effective oral communication. This notable gap highlights a lack of integration between technological tools and the development of speaking skills in an academic and professional context.

This gap suggests a disconnect between assessment tools and the holistic demands of communicative competence in technical disciplines. Our study seeks to bridge this gap by focusing on how Google Forms, when used via mobile devices, can specifically improve English speaking proficiency in engineering students, aligning technological educational tools with the practical language demands of the engineering field.

III. Aims of the Study

The aim of this study is to improve the speaking skills of engineering students, specifically targeting their fluency, accuracy, and pronunciation. The study intends to employ Google Forms integrated with listening and reading tasks on mobile in classroom to evaluate their effectiveness in enhancing the speaking proficiency of students. The study evaluates effectiveness based on the following research questions:

RQ1: Is there a significant difference in fluency, accuracy, and pronunciation between the experimental group and the control group of engineering students?

RQ2: Are there changes in fluency, accuracy, and pronunciation from the pretest to the posttest within both the experimental and control groups?

RQ3: Is there a difference in the gains achieved in fluency, accuracy, and pronunciation from the pretest to the posttest among engineering students in both the experimental and control groups?

IV. Method

To assess the impact of integrated Google Forms on speaking skills in engineering students, the study was structured as an experimental pretest-posttest control group design. Participants were divided into an experimental group and a control group. The Experimental Group (EG) used

Google Forms integrated with listening and reading tasks on mobile aimed at improving speaking skills in terms of fluency, accuracy, and pronunciation, while the Control Group (CG) engaged in standard speaking practices without these integrated tasks. The instructional strategies employed in each group's sessions were carefully controlled. The effectiveness of the intervention was evaluated based on enhancements in the speaking skills of the students, with a specific focus on fluency, accuracy, and pronunciation. Both groups participated in the same overall learning activities, with the integration of Google Forms serving as the independent variable in the study.

A. Participants and Sampling

The study involved 165 first-year engineering students, comprising 105 males and 60 females. Using random sampling, the students were divided into an experimental group (N = 86) and a control group (N = 79). To assess the initial and final levels of English-speaking skills, both groups were administered a pretest and a posttest. The participants varied in their English proficiency levels, ranging from beginners to advanced, all mixed in both groups. All participants were native Hindi speakers, residing in India, and none had previously studied abroad.

B. Classroom Settings, Materials, and Tools

The study was conducted in a language laboratory equipped with a large monitor. Students were seated comfortably on benches, strategically positioned close to the instructor's podium to facilitate communication. One instructor delivered the instructional content, while a second instructor was present to assist both the students and the primary instructor. Given the large number of participants, the instructors used microphones connected to speakers to ensure that instructions were clearly audible throughout the room. The lab session lasted for 1 h and 45 min and was conducted over 3 days each week for duration of 12 weeks.

Additionally, instructors prepared 36 Google Form links specifically for the students in the experimental lab. These forms included videos that focused on critical thinking and problem solving. Multiple-Choice Questions (MCQs) were developed to correspond with the videos, assessing students' comprehension and analytical skills. Moreover, each form also contained a reading passage, featuring both persuasive and technical texts, accompanied by MCQs designed to evaluate students' understanding of the material presented in the passages.

C. Treatment

In the experimental group, instructors organized students into groups, each consisting of 4–5 members. These groups were carefully composed to include at least two students who demonstrated higher English proficiency, thereby enhancing overall group dynamics. After seating arrangements were finalized, an instructor distributed Google Form link in a group of WhatsApp containing a video clip of 4–5 min and a reading passage of 200–250 words. This provision of diverse linguistic inputs aligns well with established educational theories. Swain's Output Hypothesis [49] highlights that producing language through output helps learners internalize and deepen their understanding of language inputs through active engagement and interaction [49]. Similarly, Paivio's Dual Coding Theory [50] supports the integration of multimedia inputs, positing that processing verbal and visual information simultaneously boosts cognitive processing and facilitates the retention and retrieval of information, which are crucial for effective language production [50]. These methodologies contribute significantly to creating a linguistically rich environment conducive to developing speaking skills. Students engaged with the materials and were required to answer multiple-choice questions related to the content on the Google Form on mobile device within a 30-minute window to complete and submit their responses.

Upon submitting their Google Forms, students engaged in a 10-minute discussion centered on the video and reading passage to enhance comprehension and foster active group participation. Instructors also encouraged peer feedback during this discussion to address grammar and pronunciation errors. Following the initial discussion, a question-and-answer session related to the materials was conducted for the remaining time in the language lab. Initially, responses were solicited from students with higher English proficiency to establish a supportive environment for participation. Gradually, students with lower proficiency levels were also encouraged to participate. Instructors provided additional feedback on grammar and pronunciation to further aid improvement. This structured approach ensured that all students had the opportunity to express their understanding and contribute to the discussion, thereby creating an inclusive environment that facilitated the development of speaking skills across different levels of proficiency.

In the control group, the Communicative Language Teaching (CLT) approach was applied to enhance English proficiency, focusing on fluency, accuracy, and pronunciation. This method emphasizes interaction and real-life communication through activities such as role-plays, simulations, and problem-solving tasks. For fluency, students engaged in timed speaking drills and group discussions to promote spontaneous speech. Accuracy was integrated into these communicative practices with targeted grammar corrections and vocabulary exercises provided after interactive sessions. Pronunciation improvement was addressed through phonetic drills, minimal pair exercises, and listening activities to refine sound distinction and articulation. Throughout these sessions, instructors facilitated a dynamic learning environment, offering feedback and language input to bolster students' confidence and communicative competence in English, ensuring that each aspect fluency, accuracy, and pronunciation was systematically developed in context.

D. Data Collection and Analysis

Data were collected through pretests and posttest at the start and end of the intervention, using the same conditions but different prompts to measure the impact of the interventions on participants' English-speaking skills. Participants in both the experimental and control groups were required to describe a randomly selected picture from a set of ten, within a three-minute timeframe, focusing on fluency, accuracy, and pronunciation. The sessions were recorded using a high-quality digital audio recorder to capture detailed

aspects of each participant's speech. This consistent assessment approach across the tests ensured that changes in the participants' oral English skills were measured accurately.

The speaking performances of the participants were evaluated based on three dimensions: fluency, accuracy and pronunciation employing the assessment framework derived from Sun's *et al.* [51] study. Before the commencement of the experiment, two evaluators (who were faculty members having PhD in English Language Teaching and three years of experience of teaching English communication) underwent training to assess these particular components. Assessors in the study were rigorously trained to ensure consistency and accuracy in evaluating fluency, accuracy, and pronunciation. The training program included an initial familiarization with the detailed scoring rubric, followed by calibration sessions where assessors independently evaluated recordings from a pilot study and then reconciled scoring discrepancies under supervision. Inter-rater reliability was systematically measured by having assessors score additional recordings and analyzing the consistency of their evaluations statistically. Regular feedback sessions were held throughout the study to maintain assessment standards and address any emerging discrepancies in scoring, ensuring a high level of reliability in the assessment process. Throughout the evaluation process, all audio-recordings were audio-recorded and successively assessed by two raters. Accuracy was assessed on a scale from 0 (incorrect/irrelevant) to 1 (correct/relevant). The process of assessing fluency involved counting the sentences produced, utilizing a scoring framework that varied from 0 (indicating no sentences), 1 (for a single sentence), 2 (for the creation of two to three sentences), and 3 (for the production of four or more sentences). Pronunciation was scored on how clear and comprehensible the spoken English was, from 0 (incomprehensible) to 1 (comprehensible). This structured and detailed evaluation method ensured assessment of each participant's speaking proficiency, providing robust and reliable results.

E. Statistical Analysis of Data

In the study, a MANOVA (Multivariate Analysis of Variance) was employed to analyze the data, chosen specifically for its efficacy in handling repeated observations of the same subjects under different conditions over time. This statistical approach is ideal for assessing changes in speaking skills fluency, accuracy, and pronunciation across pretest and posttest within the same participants, effectively minimizing variability due to individual differences. The MANOVA allows for the evaluation of main effects of time, conditions (experimental vs. control), and their interaction, which is crucial for determining whether changes in speaking skills differ significantly between groups subjected to the intervention and those that were not. By analyzing multiple time points, this test also identifies which components of the intervention most significantly impact language proficiency, providing a comprehensive view of the intervention's effectiveness. This method ensures that the study's conclusions regarding the improvement in speaking skills due to the intervention are statistically substantiated and reliable.

V. Results of the Study

The Multivariate Analysis of Variance (MANOVA) highlighted significant main effects across different linguistic performance metrics. Fluency (Mean (M) = 7.20, Standard Deviation (SD) = 0.20) and accuracy (M = 7.00, SD = 0.15) were rated higher than pronunciation (M = 6.50, SD = 0.30), with a significant main effect of measure, Frequency (F) (2, 84) = 6.830, p = 0.002, partial eta squared (η^2p) = 0.140 (Fig. 1).

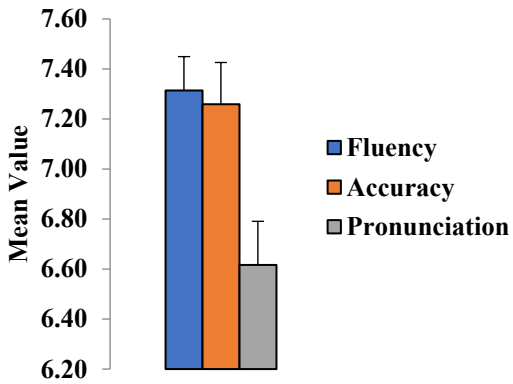

Fig. 1. Variations across linguistic measures.

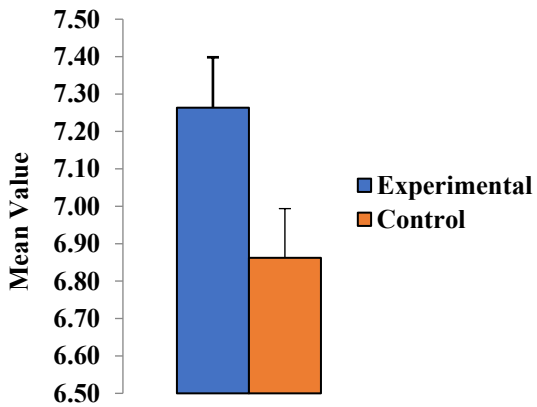

Fig. 2. Variation across groups (experimental & control).

Additionally, the analysis revealed a significant main effect of group on the outcomes which shows that the experimental group (M = 7.30, SD = 0.10) scored higher on average than the control group (M = 7.00, SD = 0.15), with an F (1, 85) = 4.411, p = 0.039, and a partial η^2p = 0.049 (Fig. 2). This difference underscores that the group membership significantly influenced the results, with the experimental group benefiting more from the interventions applied compared to the control group.

Furthermore, the analysis demonstrated a significant main effect for the test conditions with the posttest mean score (M = 7.60, SD = 0.10) substantially higher than the pretest (M = 6.80, SD = 0.15), F (1, 85) = 30.362, p < 0.001, η^2p = 0.263 (Fig. 3). This marked improvement from pretest to posttest underscores that the interventions implemented between the two testing periods had a significant and positive effect on the outcomes.

Furthermore, the interaction between measures and groups were significant where the experimental group consistently outperformed the control group across all measures: accuracy, fluency, and pronunciation. The interaction was statistically significant, yielding an F (2, 84) = 17.743, p < 0.001, η^2p = 0.297. Specifically, the experimental group achieved higher mean scores in accuracy (M = 8.00 vs. M = 7.00), fluency (M

= 7.50 vs. M = 7.00), and pronunciation (M = 7.40 vs. M = 7.00) compared to the control group (Fig. 4). The results demonstrated a significant interaction between the measures and groups, with the experimental group consistently outperforming the control group across all evaluated metrics. This notable difference underscores the effectiveness of the interventions applied to the experimental group, illustrating that the tailored measures significantly enhanced performance in all linguistic aspects tested.

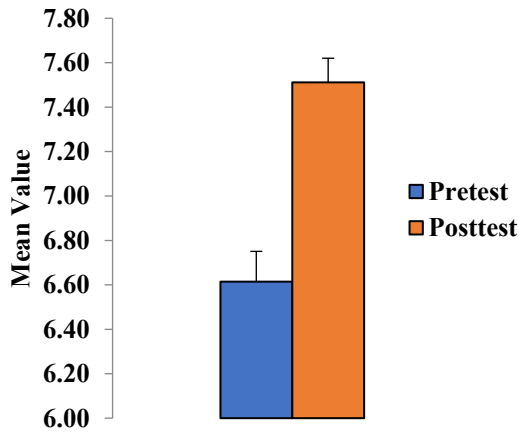

Fig. 3. Variation across tests (pre-and posttest).

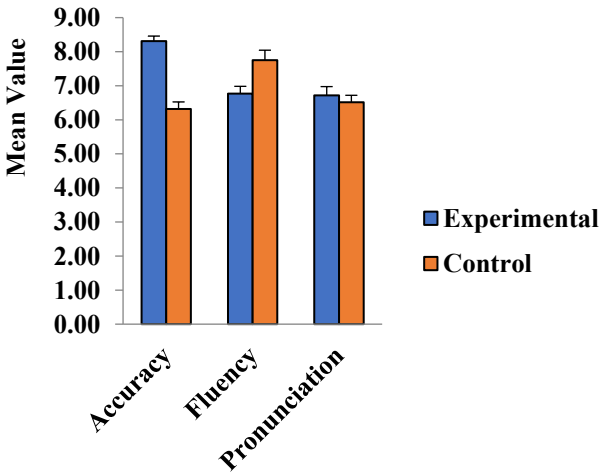

Fig. 4. Variation in groups across three linguistic measures.

The significant improvements observed from pretest to posttest across all measures i.e. accuracy, fluency, and pronunciation were attributed to the interventions implemented rather than just general learning effects. This assertion is supported by the interaction between the type of test and the measure, which showed significant effects, with an F (2, 84) = 4.871, p = 0.010, η^2p = 0.104. Specifically, posttest scores increased to M = 8.00 from M = 7.00 in accuracy, to M = 7.50 from M = 6.50 in fluency, and to M = 7.00 from M = 6.40 in pronunciation (Fig. 5). These substantial improvements highlight that the specific interventions and testing conditions played a critical role in enhancing these linguistic capabilities, indicating that the targeted interventions effectively addressed and improved specific aspects of language performance.

The interactions between group and test as well as the three-way interaction involving measure, group, and test were not statistically significant in this study. Specifically, the interaction between group and tests yielded an F (1, 85) = 2.691, p = 0.105, and η^2p = 0.031, indicating that the differences between the groups did not have a significant impact on the test outcomes. Additionally, the three-way interaction among measure, group, and tests produced an F (2, 84) = 1.016, p = 0.366, and η^2p = 0.024, showing that the combined effects of the type of measure, group distinctions, and testing conditions did not significantly influence the study's results. These findings highlight that neither the group differences nor the specific testing conditions, alone or in combination, significantly affected the overall outcomes of the study.

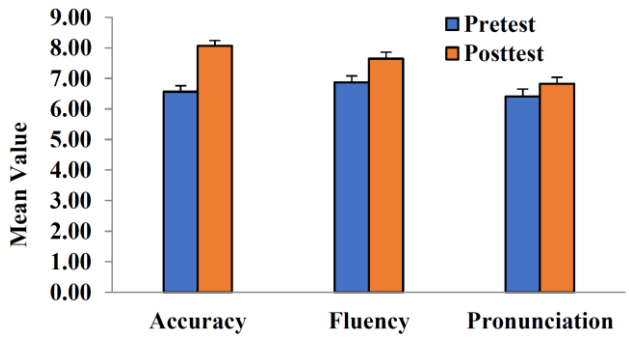

Fig. 5. Variation in measure across test (pre-and posttest).

The Multivariate Analysis of Variance (MANOVA) in this study revealed significant main effects and interactions affecting linguistic performance metrics such as fluency, accuracy, and pronunciation. The analysis showed that fluency and accuracy were rated higher than pronunciation with significant main effects indicating variations in outcomes across different measures and testing conditions. Notably, the experimental group outperformed the control group across all metrics, benefiting more from the interventions applied, which significantly enhanced their performance in accuracy, fluency, and pronunciation. Additionally, the posttest scores improved markedly over the pretest scores, indicating that the interventions, rather than mere exposure or practice effects, were effective in enhancing specific linguistic capabilities. However, the interactions between group and test conditions and the three-way interaction involving measure, group, and tests were not statistically significant, suggesting that while interventions were effective, group differences and the specific combination of testing conditions did not independently affect the outcomes. These findings underscore the effectiveness of targeted interventions in improving linguistic performance, highlighting their importance in educational and training context.

VI. Discussion

The study aimed to enhance the speaking skills specifically fluency, accuracy, and pronunciation of engineering students by employing Google Forms integrated with listening and reading tasks on mobile devices within classroom settings. The findings revealed that there were significant improvements in the experimental group compared to the control group, addressing RQ1 by demonstrating notable enhancements in all three targeted linguistic skills. For RQ2, both the experimental and control groups showed significant improvements from the pretest to the posttest, indicating the

effectiveness of the integrated mobile tasks in developing speaking skills over time. Regarding RQ3, the experimental group displayed significantly greater gains from the pretest to the posttest across fluency, accuracy, and pronunciation compared to the control group, suggesting that the specific interventions applied were particularly effective in fostering substantial improvements in these areas. These results underscore the utility of mobile-assisted language learning tools in improving the speaking proficiency of engineering students, supporting the study's aim to leverage technology in educational enhancements.

The study's findings align with current study on Mobile-Assisted Language Learning (MALL), emphasizing the effectiveness of integrating mobile technologies in educational settings to enhance language proficiency [52]. According to Kukulska-Hulme and Shield [53], MALL applications have been shown to improve language skills by providing students with flexible access to interactive and contextual resources. The significant improvements in fluency, accuracy, and pronunciation observed in the experimental group support Hockly's [54] assertion that mobile devices can facilitate tailored linguistic exercises that address individual learning needs and preferences, thereby enhancing specific language competencies [55]. Moreover, the substantial gains observed from the pretest to the posttest within both the experimental and control groups resonate with findings from Stockwell and Hubbard's [56] study, which demonstrated that regular exposure to language tasks through mobile devices leads to consistent improvements in language skills. This incremental improvement underscores the role of sustained engagement and practice facilitated by mobile devices in language learning, as discussed by Burston [57], who highlights the pedagogical benefits of integrating mobile technology into language education to support continuous learning and assessment. Furthermore, the greater improvements in the experimental group, as compared to the control group, align with the principles outlined by Crompton and Burke [58], who argue that well-designed mobile learning interventions that integrate listening and reading tasks can lead to higher learning outcomes by engaging learners in meaningful and authentic language use scenarios. This suggests that the specific interventions used in this study were effectively tailored to enhance the linguistic outcomes of engineering students, providing them with the necessary skills to improve their fluency, accuracy, and pronunciation.

The significant findings of the study are also in line with a growing body of research underscoring the effectiveness of such technologies in education. Studies like those by Kukulska-Hulme *et al.* [53] have highlighted that mobile devices not only facilitate access to learning materials but also enhance learner engagement through interactive and personalized learning environments [59]. These aspects are critical in language learning, where engagement and personalization can lead to substantial improvements in fluency, accuracy, and pronunciation, as seen in this study. Furthermore, studied by Traxler and Kukulska-Hulme [60] supports the notion that mobile learning can significantly enhance learning outcomes by providing learners with the ability to access learning materials anytime and anywhere, thus increasing opportunities for practice and exposure to the target language. This is particularly relevant to the improvements from pretest to posttest noted in both the experimental and control groups, indicating effective ongoing engagement with the language facilitated by mobile technologies. Moreover, the previous studies also point out the importance of integrating specific pedagogical strategies into mobile learning environments to maximize their effectiveness. For example, Goktas [61] and Usama *et al.* [62] emphasizes the potential of podcasting and mobile-assisted oral feedback to enhance pronunciation and speaking fluency, which aligns with the findings from the experimental group that showed greater linguistic gains. Similarly, Godwin-Jones [63] suggests that mobile applications that incorporate gamification and interactive elements can lead to higher motivation and better language acquisition, which could explain the significant enhancements observed in the experimental group. Additionally, a study by Demouy *et al.* [64] on the use of mobile tools for language learning emphasizes the role of audio and visual aids in improving pronunciation, suggesting that the integration of these elements in mobile apps could have contributed to the pronounced improvements in pronunciation among the participants. This aligns with the study's findings where the integration of listening and reading tasks in mobile-assisted learning frameworks proved particularly effective.

The study's findings directly support Constructivist Learning Theory by demonstrating that the use of integrated Google Forms and mobile-assisted tasks effectively enhanced students' speaking skills, mirroring Piaget's theory that learners construct knowledge through active engagement with the material [15]. More significantly, the notable improvements in fluency, accuracy, and pronunciation from the pretest to the posttest within the experimental group exemplify Vygotsky's concept of the zone of proximal development. This concept suggests that students can achieve higher learning outcomes with the aid of supportive and interactive educational tools that extend beyond traditional learning methods [16]. The findings showcase how technology-facilitated interventions can provide the necessary scaffolding, enabling students to reach higher levels of linguistic proficiency. These outcomes not only affirm the effectiveness of such technological integrations in fostering significant linguistic improvements but also highlight the importance of designing learning environments that are rooted in constructivist principles, where students actively construct their learning experiences, thereby making the learning process more engaging and effective [65–68].

Furthermore, the study's findings not only resonate with Constructivist Learning Theory but also align with Bandura's Social Learning Theory and Swain's Output Hypothesis and Mayer's Cognitive Theory of Multimedia Learning. The use of Google Forms integrated with mobile-assisted tasks exemplifies Piaget's principle of active learning through direct interaction [15], and Vygotsky's concept of the zone of proximal development, which underscores the importance of scaffolded support and social interaction in learning [16]. Additionally, Bandura's Social Learning Theory highlights the role of observational learning, where students might have enhanced their linguistic skills by mimicking successful peer interactions [69], and Swain's Output Hypothesis emphasizes the importance of producing language as a mechanism for

learning [15]. Mayer's Cognitive Theory of Multimedia Learning further supports these findings by suggesting that well-designed multimedia instructional messages combine verbal and visual information to foster deeper learning [70]. This theory is particularly relevant as the mobile-assisted tasks likely utilized multimedia elements that helped students integrate and apply new language skills more effectively, enhancing overall communicative competence. The convergence of these theories within the study illustrates the effectiveness of a multimodal, interactive approach in educational settings, providing robust theoretical support for the use of technology-enhanced learning tools to improve language proficiency [71].

These findings affirm the potential of mobile-assisted learning tools to not only improve language learning outcomes but also to provide flexible, engaging, and effective educational experiences that align with modern pedagogical strategies, thus supporting the integration of such technologies in educational settings, particularly in engineering education where practical, applied learning strategies are valued.

VII. Conclusion

The study's findings underscore the effectiveness of mobile-assisted language learning tools in enhancing speaking skills among engineering students. The findings revealed notable improvements in fluency, accuracy, and pronunciation through the integration of Google Forms with listening and reading tasks on mobile devices. These results are robustly supported by educational theories such as Constructivism, which emphasizes learning through active interaction; this was evident in the improved learning outcomes observed when students engaged actively with problem-solving tasks. Similarly, Bandura's Social Learning Theory highlights the benefits of observational learning, which corresponds with our findings that students who observed peer problem-solving strategies adapted these methods effectively, enhancing their task performance. Additionally, Mayer's Cognitive Theory of Multimedia Learning suggests that combining verbal and visual information enhances comprehension and retention; our study supports this with data showing that students had better retention rates when instructional methods integrated both textual and visual information. The application of these theories in the experimental design illustrates that engaging, multimodal educational tools can significantly improve linguistic proficiency, preparing students for professional environments where English is the lingua franca. The findings suggest that similar mobile-based methodologies could enhance learning outcomes in other disciplines, particularly those requiring interactive and multimodal engagement. Overall, this research adds to the growing body of work on mobile-assisted language learning, highlighting the shift towards more dynamic, interactive, and effective learning methodologies that can cater to diverse learning needs and promote higher educational achievement.

The study on Mobile-Assisted Language Learning (MALL) exhibits several limitations that affect its findings and offers numerous avenues for future research. Firstly, external variables such as students' prior English exposure, motivation levels, and varied learning environments were not fully controlled, which might have impacted the assessment of the true efficacy of the MALL interventions. Additionally, the study's focus on engineering students in India limits its generalizability, as the findings may not apply to students in other academic disciplines, cultural contexts, or those with varying English proficiency levels. This limitation should be more explicitly acknowledged, as it restricts the applicability of the results to broader or more diverse student populations. Future studies should aim to include a more heterogeneous sample to examine cross-contextual effectiveness and promote generalizability. Furthermore, the reliance on quantitative data without incorporating qualitative feedback from participants means deeper insights into the participants' engagement and overall learning experiences are missing. The absence of qualitative data limits the depth of interpretation, as it does not allow for a nuanced understanding of learners' perceptions, motivations, or contextual challenges encountered during the intervention. Including narrative responses or reflective journals in future studies could shed light on learners' emotional and cognitive responses to MALL tools.

For future research, it is crucial to include detailed assessments of external variables at the outset and strive to standardize or comprehensively document learning environments. This will help isolate the effects of MALL and enhance the study's validity and applicability. Examining the long-term retention of language skills post-intervention would provide insights into the sustainability of MALL impacts. Integrating advanced technological features, such as artificial intelligence and machine learning, could personalize learning experiences and potentially increase the efficacy of MALL interventions. Additionally, replicating this study in diverse settings and with students of different proficiency levels would help determine the effectiveness of MALL tools like Google Forms across a wider range of educational environments and student populations. Future studies should also include qualitative methods such as interviews, focus groups, or surveys with both students and instructors. This mixed-methods approach would enhance interpretive depth and provide valuable contextual information that cannot be captured through quantitative data alone. In addition, triangulating findings from different data sources can improve the credibility and validity of research outcomes. This approach would enrich the findings with personal narratives and experiential data, providing a more comprehensive understanding of how interventions are perceived and their practical impacts on learning. Together, these measures would provide a more holistic view of the educational process and enhance the methodological robustness of future MALL research.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Dr. Sohaib Alam and Dr. Amir supervised the whole research development and took the lead in writing the manuscript. Dr. Anam Shams and Dr. Mohammad Usama developed the theoretical formalism and wrote the manuscript with support from Ms. Bahia Khalifa Ibrahim Mohammed

and Ms. Sameena Banu. All authors provided critical feedback and helped shape the research, analysis, and manuscript. All authors had approved the final version.

FUNDING

This study is supported via funding from Prince Sattam Bin Abdulaziz University project number (PSAU/2025/R/1447).

ACKNOWLEDGMENT

The authors extend their appreciation to Deanship of Scientific Research, Prince Sattam Bin Abdulaziz University and wish to thank to the participants who participated voluntarily in the present study.

REFERENCES

[1] D. Crystal, *English as A Global Language*, Cambridge: Cambridge University Press, 2003, ch. 2.

[2] D. Graddol, *English Next*, Singapore: British Council, ch. 1, 2006.

[3] M. Usama *et al.*, "Web-based vs. mixed mode instruction utilizing e-learning via LMS: A comparative study," *International Journal of Information and Education Technology*, vol. 14, no. 4, pp. 612–619, April 2024.

[4] P. C. Borstorff, M. B. Marker, and D. S. Bennett, "Online recruitment: Attitudes and behaviors of job seekers," *Journal of Strategic e-Commerce*, vol. 5, no. 2, pp. 1–23, 2007.

[5] T. Hutchinson and A. Waters, *English for Specific Purposes*, Cambridge: Cambridge University Press, ch. 1, 1987.

[6] P. C. Robinson, *ESP Today: A Practitioner's Guide*, Hoboken: Prentice Hall, ch. 1, 1991.

[7] L. Vandergrift, "Recent developments in second and foreign language listening comprehension research," *Language Teaching*, vol. 40, no. 3, pp. 191–210, 2007.

[8] S. Alam, "Pedagogical implications in EFL classrooms: A reflective praxis of vocabulary strategies and techniques," *Journal of Language Teaching and Research*, vol. 14, no. 5, pp. 1422–1429, 2023.

[9] S. Alam, "Measuring the effects of mobile and social networking technology on the enhancement of English language skills: A comparative study," *International Journal of Interactive Mobile Technologies*, vol. 19, no. 1, pp. 79–92, 2025.

[10] M. Ajmal *et al.*, "Investigating teacher-student emotional dynamics in English language teaching: Examining co-regulation techniques and their impact on learning outcomes," *World Journal of English Language*, vol. 15, no. 3, pp. 215–224, 2025.

[11] F. Ahmad and S. Alam, "Role of achievement motivation and metacognitive strategies use for defining self-reported language proficiency," *World Journal of English Language*, vol. 14, no. 6, pp. 77–86, 2024.

[12] S. Alam *et al.*, "Practice and principle of blended learning in ESL/EFL pedagogy: Strategies techniques and challenges," *International Journal of Emerging Technologies in Learning*, vol. 17, no. 11, pp. 225–241, 2022.

[13] S. Alam *et al.*, "Perception and practice of using artificial intelligence in education: An opinion based study," *XLinguae*, vol. 17, no. 1, pp. 216–233, 2024.

[14] C. C. M. Goh and A. Burns, *Teaching Speaking: A Holistic Approach*, Cambridge: Cambridge University Press, 2012.

[15] J. Piaget, *The Construction of Reality in the Child*, London: Routledge, ch. 1, 2013.

[16] L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes*, Cambridge: Harvard University Press, 1978.

[17] S. Alam *et al.*, "Utilizing process drama in education: A study of pedagogical perceptions," *XLinguae*, vol, 17, no. 2, pp. 132–149, 2024.

[18] S. Alam, F. Ahmad, and Y. N. Biryukova, "Incorporating artificial intelligence and MALL strategies in EFL classrooms: Interactive pedagogical praxis," *Journal of Education Culture and Society*, vol. 15, no. 1, pp. 181–198, 2024.

[19] S. Alam, "Efficacy of mixed model instruction to improve English language skills of business management students: An experimental study," *Journal of Education Culture and Society*, vol. 15, no. 2, pp. 387–402, Sep. 2024.

[20] B. Beg *et al.*, "Investigating the efficiency of the rotation model in improving first-year undergraduate ESL learners' writing: A quasi-experimental study," *World Journal of English Language*, vol. 15, no. 2, pp. 357–367, Dec. 2024.

[21] S. Alam *et al.*, "Reflecting the voices of EFL teachers in the world of Intelligent Computer-Assisted Language Assessment (ICALA): An insight into teacher immunity, reflective teaching, job satisfaction, and L2-teacher grit," *Language Testing in Asia*, vol. 14, no. 1, 43, Oct. 2024.

[22] S. Alam, M. R. Karim, and F. Ahmad, "Process drama as a method of pedagogy in ESL classrooms: Articulating the inarticulate," *Journal of Education Culture and Society*, vol. 11, no. 1, pp. 255–272, 2020.

[23] J. Jenkins, *English as a Lingua Franca: Attitude and Identity*, Oxford: Oxford University Press, 2007, ch. 1.

[24] B. Seidlhofer, *Understanding English as A Lingua Franca*, Oxford: Oxford University Press, ch. 1, 2013.

[25] T. M. Derwing and M. J. Munro, "Second language accent and pronunciation teaching: A research-based approach," *TESOL Quarterly*, vol, 39, no. 3, pp. 379–397, 2005.

[26] J. M. Levis, "Changing contexts and shifting paradigms in pronunciation teaching," *TESOL Quarterly*, vol. 39, no. 3, pp. 369–377, 2005.

[27] K. Kaufhold, "Conventions in postgraduate academic writing: European students' negotiations of prior writing experience at an English-speaking university," *Journal of English for Academic Purposes*, vol. 20, pp. 125–134, Dec. 2015.

[28] U. Smit, *English as a Lingua Franca in Higher Education: A Longitudinal Study of Classroom Discourse*, Berlin: Walter de Gruyter, ch. 1, 2010.

[29] N. D. Handayani, "Google form application effect on students' basic English grammar mastery," *ELP (Journal of English Language Pedagogy)*, vol. 8, no. 1, pp. 88–105, Jan. 2023.

[30] R. Rinaldi, Wiyaka, and E. F. Prastikawati, "Google form as an online assessment tool to improve the students' vocabulary mastery," *SALEE: Study of Applied Linguistics and English Education*, vol. 3, no. 1, pp. 56–71, 2022.

[31] F. Yunita, "The use of google form application as media for students' assessment," in *Proc. International Conf. on English Language Teaching (INACELT)*, 2019, pp. 118–127.

[32] Y. Kita, "Using forms quizzes to enhance students' motivation in language learning at a Japanese university," *Indonesian Journal of English Language Teaching and Applied Linguistics*, vol. 5, no. 2, pp. 219–235, 2021.

[33] H. Wibowo and A. A. Rahmah, "The use of google form as a learning evaluation tool in English lessons during pandemic COVID-19," *Akademika*, vol, 10, no. 2, pp. 437–445, Dec. 2021.

[34] S. Jazil *et al.*, "Students' attitudes towards the use of google forms as an online grammar assessment tool," in *Proc. International Conf. on English Language Teaching (ICONELT 2019)*, 2020, pp. 166–169.

[35] I. Irawansyah, "Investigating the students' work in translating recount text from Indonesia to English through google form: Morphological errors," *Journal of English Educational Study (JEES)*, vol. 7, no. 2, pp. 225–232, 2024.

[36] S. Alam *et al.*, "Analyzing facebook mobile usage: Efficacy and ESL learners writing proficiency," *International Journal of Interactive Mobile Technologies*, vol. 18, no. 3, pp. 60–74, 2024.

[37] A. S. Alharbi, A. A. Alhebshi, and Z. Meccawy, "EFL students' and teachers' perceptions of google forms as a digital formative assessment tool in Saudi secondary schools," *Arab World English Journal (AWEJ)*, vol. 7, pp. 140–154, July 2021.

[38] S. M. Alenezi, "Tertiary level English language teachers' use of and attitudes to alternative and online assessments during the COVID-19 outbreak," *International Journal of Education and Information Technologies*, vol. 16, pp. 39–49, 2022.

[39] T. R. B. Elbasyouny, "Enhancing students' learning and engagement through formative assessment using online learning tools" M.S. thesis, The British University in Dubai, Dubai, United Arab Emirates, 2021.

[40] S. Dhawan, "Online learning: A panacea in the time of COVID-19 crisis," *Journal of Educational Technology Systems*, vol. 49, no. 1, pp. 5–22, 2021.

[41] K. A. Azhar and N. Iqbal, "Effectiveness of google classroom: Teachers' perceptions," *Prizren Social Science Journal*, vol. 2, no. 2, pp. 52–66, 2018.

[42] M. E. Brown and D. L. Hocutt, "Learning to use, useful for learning: A usability study of google apps for education," *J. Usability Stud.*, vol. 10, no. 4, pp. 160–181, Aug. 2015.

[43] G. Oktay, "Perceptions of in-service EFL teachers and testing and evaluation specialists on mobile assisted language learning assessment: A qualitative case study," M.S. thesis, Middle East Technical University, Ankara, Türkiye, 2024.

[44] R. S. Gurevych, I. Y. Shakhina, and O. A. Podzygun, "Google classroom as an effective tool of smart learning and monitoring of students' knowledge in vocational schools," *Information Technologies and Learning Tools*, vol. 79, no. 5, pp. 59–72, 2020.

[45] R. Haddad and K. Youakim, "Google forms: A real-time formative assessment approach for adaptive learning," in *Proc. 2014 American Society for Engineering Education, ASEE Annual Conf. and Exposition Indiana*, 2014, 8645.
[46] S. Alarfaj, "Early childhood students' use of educational apps: A case study of Saudi teachers' perceptions and practices," Ph.D. dissertation, University of Leicester, Leicester, UK, 2021.
[47] M. Djenno, G. M. Insua, and A. Pho, "From paper to pixels: Using google forms for collaboration and assessment," *Library Hi Tech News*, vol. 32, no. 4, pp. 9–13, 2015.
[48] S. Sandhya *et al.*, "Adoption of google forms for enhancing collaborative stakeholder engagement in higher education," *Journal of Engineering Education Transformations*, vol. 33, pp. 283–289, 2020.
[49] J. Cummins and M. Swain, *Communicative Competence: Some Roles of Comprehensible Input and Comprehensible Output in Its Development*, London: Routledge, ch. 1, 1985.
[50] A. Paivio, *Mental Representations: A Dual Coding Approach*, Oxford: Oxford University Press, 1990.
[51] Z. Sun *et al.*, "Improving the English-speaking skills of young learners through mobile social networking," *Computer Assisted Language Learning*, vol. 30, pp. 304–324, 2017
[52] A. Huskova, Z. Gadusova, and R. Havettova, "Methodological aspects of online forms of teaching," *Journal of Education Culture and Society*, vol. 12, no. 2, pp. 139–152, 2021.
[53] A. Kukulska-Hulme and L. Shield, "An overview of mobile assisted language learning: From content delivery to supported collaboration and interaction," *ReCALL*, vol. 20, no. 3, pp. 271–289, 2008.
[54] N. Hockly, "Mobile learning," *ELT Journal*, vol. 67, no. 1, pp. 80–84, 2013.
[55] M. Ružić-Baf, S. Kadum, and K. Kvaranta, "Online teaching and grading during the COVID-19 pandemic attitudes of Croatian students," *Journal of Education Culture and Society*, vol. 12, no. 2, pp. 399–411, Sep. 2021.
[56] G. Stockwell and P. Hubbard. (2013). Some emerging principles for mobile-assisted language learning. *The International Research Foundation for English Language Education*. [Online]. Available: http://www.tirfonline.org/wp-content/uploads/2013/11/TIRF_MALL_Papers_StockwellHubbard.pdf
[57] J. Burston, "Twenty years of MALL project implementation: A meta-analysis of learning outcomes," *ReCALL*, vol. 27, no. 1, pp. 4–20, 2015.
[58] H. Crompton and D. Burke, "The use of mobile learning in higher education: A systematic review," *Computers & Education*, vol. 123, pp. 53–64, 2018.
[59] A. Kobylarek, "The internet as a new chance for academic communities," *Journal of Education Culture and Society*, vol. 6, no. 1, pp. 5–8, 2015.
[60] J. Traxler and A. Kukulska-Hulme, *Mobile Learning: The Next Generation*, London: Routledge, 2015.
[61] Y. Goktas, "Mobile learning of English speaking and listening skills via smartphones," Ph.D. dissertation, University of Birmingham, Birmingham, UK, 2023.
[62] M. Usama *et al.*, "The impact of rotation model on minimizing inflectional morphemes errors in English writing: A comparative study of error analysis," *Theory and Practice in Language Studies*, vol. 14, no. 2, pp. 307–318, 2024.
[63] R. Godwin-Jones, "Smartphones and language learning," *Language Learning & Technology*, vol. 21, no. 2, pp. 3–17, 2017.
[64] V. Demouy *et al.*, "Why and how do distance learners use mobile devices for language learning?" *The EuroCALL Review*, vol. 24, no. 1, pp. 10–24, 2016.
[65] A. Kobylarek, M. Madej, and M. Roubalová, "Communication community in the prefigurative world," *Journal of Education Culture and Society*, vol. 13, no. 2, pp. 7–16, 2022.
[66] M. S. Amir *et al.*, "Incorporating 'flipped classroom model': Developing English speaking skills of engineering students," *International Journal of Information and Education Technology*, vol. 15, no. 4, pp. 686–695, 2025.
[67] S. Alam, "Effects of multimedia inputs on improving the grammatical accuracy of students' speaking skills: An experimental study," *Theory and Practice in Language Studies*, vol. 15, no. 5, pp. 1579–1590, 2025.
[68] S. A. Fakir *et al.*, "LLMs as effective localised materials for English language learners: A comprehensive framework," *Journal of Language Teaching and Research*, vol. 16, no. 3, pp. 975–985, 2025.
[69] A. Bandura. Social learning theory. [Online]. Available: https://www.asecib.ase.ro/mps/Bandura_SocialLearningTheory.pdf
[70] R. E. Mayer, "Multimedia learning," *Psychology of Learning and Motivation*, vol. 41, pp. 85–139, 2002.
[71] S. Alam and M. Usama, "Does e-feedback impact minimizing ESL writing errors? An experimental study," *Int. J. Emerg. Technol. Learn.*, vol. 18, no. 4, pp. 156–169, 2023.

Copyright © 2025 by the authors. This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited (CC BY 4.0).