Journal of Hypermedia & Technology-Enhanced Learning
Vol. 3, No. 3, October (2025), Pages 262–282
e-ISSN: 2985–9166 | 10.58536/j-hytel.193

RESEARCH ARTICLE

A Mobile Vocabulary Learning App for Engineering Contexts: Gamification, Self-Directed Learning, and User Progress Tracking

Anita Nursi[1]*, Resmi Darni[2], Dony Novaliendry[2]

[1] Department of Informatics Engineering, Faculty of Engineering, Universitas Negeri Padang, Padang, **Indonesia**
[2] Department of Electronics Engineering, Faculty of Engineering, Universitas Negeri Padang, Padang, **Indonesia**

Corresponding Author: anitanursi@student.unp.ac.id

This article contributes to:

ABSTRACT

Engineering students frequently face challenges in mastering technical English vocabulary due to its context-dependent and specialized nature. To address this issue, this study developed a mobile application that facilitates self-directed learning of domain-specific vocabulary through gamified activities. The application was designed using the Flutter framework and integrated with Firebase for real-time data management and user tracking. It features two interactive games—*Word Guess* and *Word Match*—as well as text-to-speech functionality, a limited hint system, and visual progress tracking through mastery counts and progress bars. Vocabulary items are organized into three thematic categories: General Terms, Tools, and Instructions, each structured through JSON-based data management for scalability and ease of maintenance. Empirical evaluations involving expert review yielded a high validity score (M = 4.6/5), confirming the application's pedagogical soundness and technical stability. The integration of gamification and progress visualization significantly enhanced learner motivation, autonomy, and engagement. This study presents a replicable model for integrating Flutter–Firebase development with instructional design principles to improve technology-enhanced language learning in engineering education.

KEYWORDS

Mobile application; technical vocabulary; gamification; self-directed learning; Flutter; engineering education

Received: May. 26, 2025; *Revised:* Jun. 10, 2025; *Accepted:* Sep. 17, 2025; *Published Online:* Oct. 14, 2025

How to Cite: Nursi, A., Darni, R., & Novaliendry, D. (2025). A Mobile Vocabulary Learning App for Engineering Contexts: Gamification, Self-Directed Learning, and User Progress Tracking. *Journal of Hypermedia & Technology-Enhanced Learning*, *3*(3), 262–282. https://doi.org/10.58536/j-hytel.193

Published by Sagamedia Teknologi Nusantara

1. INTRODUCTION

English functions as the primary medium of communication in global academic, industrial, and research settings. Within engineering disciplines, proficiency in English, particularly in domain-specific vocabulary, is indispensable for accessing international literature, interpreting technical documentation, and participating in professional collaborations. However, engineering students often

encounter substantial difficulties in mastering specialized vocabulary due to its high level of abstraction, context dependency, and limited exposure in traditional classrooms. Vocabulary proficiency is, therefore, a more reliable indicator of professional communicative competence than grammatical accuracy or general fluency, especially in technical and engineering education contexts.

The evolution of Mobile-Assisted Language Learning (MALL) has provided new pathways for enhancing vocabulary learning by leveraging the ubiquity and portability of mobile devices. MALL enables personalized, flexible, and self-paced study, fostering learner autonomy and engagement beyond formal classroom settings. A growing body of research has highlighted that integrating gamification, through interactive elements such as points, challenges, badges, and quizzes, can significantly enhance vocabulary retention, motivation, and learner satisfaction. Fithriani [1] demonstrated that mobile-assisted gamified activities led to higher vocabulary gains and improved learner motivation among Indonesian EFL students. Similarly, Zhang [3] found that gamified environments such as Quizlet, when implemented under cooperative learning conditions, yielded greater vocabulary acquisition outcomes than competitive or self-regulated modes, underscoring the role of social engagement in gamified learning.

Complementing these findings, Maraza-Quispe et al. [4] emphasized that gamification platforms, such as Kahoot and Quizizz, not only enhance motivation but also improve feedback processes and learning analytics, which are vital to adaptive instruction. From a pedagogical standpoint, gamified mobile applications thus serve as effective environments for fostering self-directed and reflective learning. La et al. [2] further validated this perspective through the Integrative Model of Behavior Prediction, illustrating that students' attitudes, social norms, and self-regulation skills significantly predict the actual use of mobile technology for self-directed language learning. This theoretical link reinforces the notion that technology-mediated gamified learning fosters both intrinsic motivation and behavioral intention to engage in autonomous vocabulary practice.

Recent studies have extended this discussion within developing-country contexts. Maryani et al. [5] found that gamified mobile-based learning improved engagement and instructional quality in remote Indonesian schools, highlighting its scalability and accessibility in regions with limited educational infrastructure. Such results affirm that gamified mobile learning applications hold considerable promise for bridging educational equity gaps while maintaining pedagogical quality.

Grounded in these theoretical and empirical perspectives, the present study aims to design and develop a mobile application for technical English vocabulary learning tailored to engineering contexts. The system integrates gamified learning modules (Word Guess and Word Match), text-to-speech, limited hints, and real-time progress tracking. Built using Flutter for cross-platform deployment and Firebase for cloud-based backend management, the prototype emphasizes modularity, scalability, and learner autonomy. By combining gamification, self-directed learning, and progress visualization, the study contributes a replicable model that bridges educational pedagogy and mobile application development in the field of Technology-Enhanced Learning (TEL), addressing a critical gap in domain-specific vocabulary acquisition for engineering students.

2. METHODS

This study employed the prototyping method, an iterative software development approach emphasizing continuous refinement through successive prototype versions. This approach allows developers to iteratively validate both functional and pedagogical aspects of the system, making it particularly suitable for educational technology research and development [6], [7]. It enables early user engagement, facilitates pedagogically aligned design decisions, and reduces implementation risk through systematic feedback and evaluation cycles. As shown in Figure 1, the prototyping process in this study consisted

of five iterative stages: (1) *communication*, (2) *quick planning*, (3) *modeling quick design*, (4) *construction of the prototype*, and (5) *deployment with feedback*. Each phase formed a feedback loop that ensured both the technical functionality and instructional effectiveness of the developed application were continually refined before final deployment.

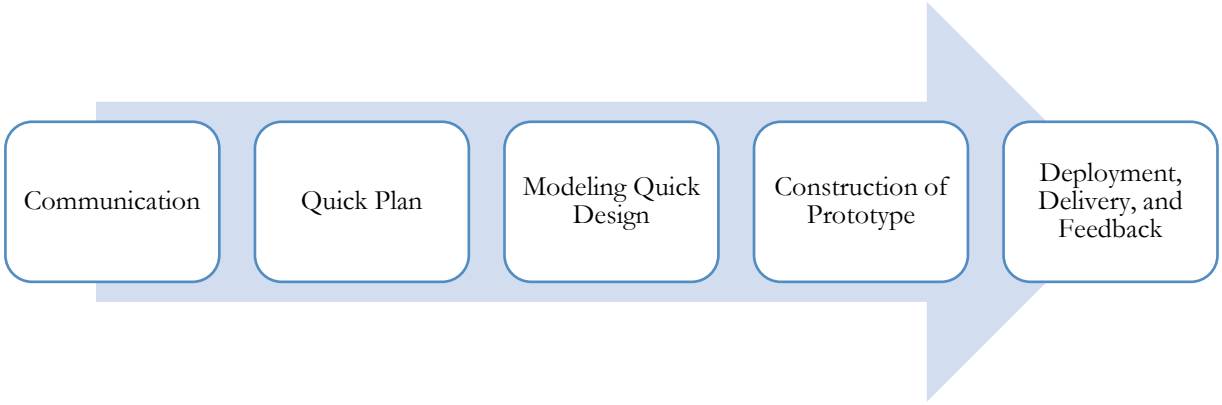


Figure 1. Prototyping method

2.1. Communication

In the initial Communication stage, a comprehensive requirements analysis was conducted to identify both the functional needs and technological components essential for developing the mobile vocabulary learning application. This phase ensured that the resulting system would effectively address the linguistic and pedagogical needs of engineering students while aligning with intended learning outcomes such as: (1) fostering self-directed learning; (2) promoting engagement through gamification; and (3) enabling measurable vocabulary progress tracking.

The analysis also evaluated the feasibility of various development tools and frameworks, particularly Flutter, Firebase, and JSON-based data management, to guarantee efficient implementation and maintainability. The core functional requirements identified during this phase are summarized in Table 1, which presents a description, pedagogical purpose, and associated technology for each feature. These requirements served as the foundation for subsequent design and prototype construction.

Table 1. Requirement analysis

Requirement	Description
User Authentication	Enables users to log in and log out of the application securely.
Vocabulary Categories	Displays vocabulary in three categories: general terms, tools, and instructions.
Word Guess Game	Presents a word guessing quiz with letter-based input, auto-detection, and limited hints.
Word Match Game	Provides a matching game to pair words with their meanings using interactive columns.
Text-to-Speech (TTS)	Automatically pronounces the word when the correct answer is given.
Mastered Word Storage	Saves words that users have guessed or matched correctly to a "Mastered Words" list.
Progress Visualization	Displays a progress bar and mastered word ratio on the home page.

2.2. Quick Plan

The Quick Plan stage defined the logical structure and workflow of the vocabulary learning application. Its purpose was to establish a procedural blueprint to guide development and ensure that each system component aligned with pedagogical and functional objectives. By planning the process flow at this stage, potential design issues could be anticipated early, improving development efficiency and user experience.

2.2.1. Flowchart

A flowchart is a graphical tool used to represent the sequence of processes, decision points, and operations within a system. It helps analysts and developers decompose complex workflows into manageable steps while evaluating alternative operational paths.

In this study, the flowchart served as a conceptual model that illustrated the user journey and system logic from login to mastery tracking. As shown in Figure 2, the workflow begins with user authentication, followed by category selection. After choosing a word, the learner completes two interactive stages: the Word Guess Game and the Word Match Game. Once both games are completed, the correctly learned words are stored in the Mastered Words list, contributing to user progress tracking.

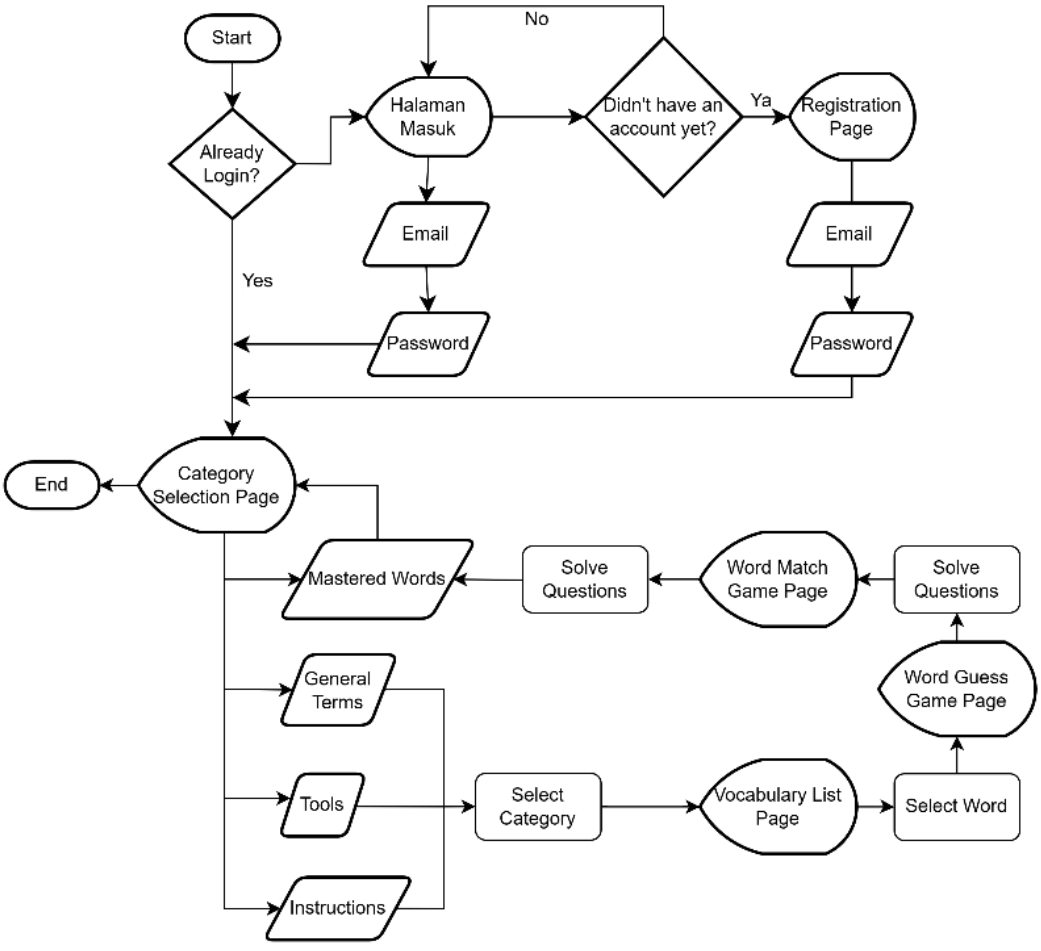


Figure 2. Flowchart of the vocabulary learning application

2.3 Modeling Quick Design

The Modeling Quick Design phase transformed the functional requirements into structured visual representations using Unified Modeling Language (UML) diagrams. These diagrams validated the consistency between requirements and the intended system architecture. Three primary UML diagrams were developed to capture different perspectives of the system: the Class Diagram, the Component Diagram, and the Activity Diagram.

2.3.1 Class Diagram

The class diagram illustrates the relationships among the core classes within the vocabulary learning application. As shown in Figure 3, the system comprises several key courses. The User class represents individual users of the application, including authentication data and personal progress. The Vocabulary class stores the available vocabulary items categorized into *general terms*, *tools*, and *instructions*. The GameSession class models a complete learning session, in which users select words from a specific category and participate in two interactive games (*Word Guess* and *Word Match*), with a maximum of five hints available in the Word Guess game. The GameProgress class records detailed user performance within a session, generating one record per word (e.g., a session with five words produces five entries). Finally, the MasteredWords class stores vocabulary items that have been successfully learned through the completion of both games, serving as a record of user achievement and vocabulary mastery.

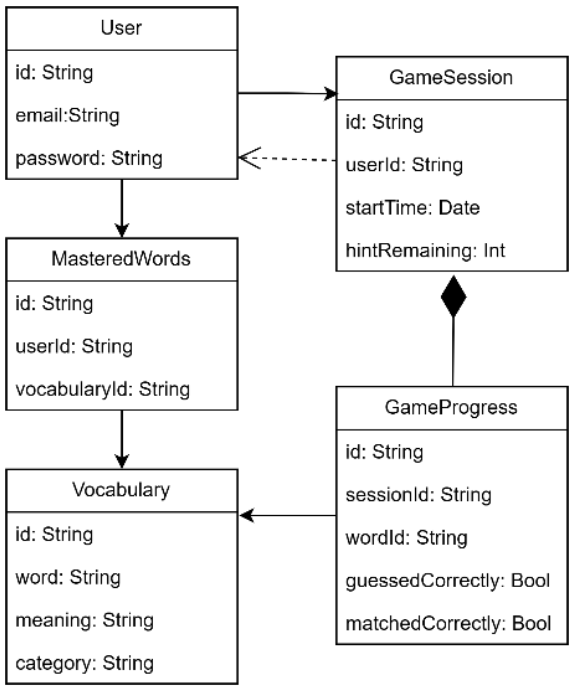


Figure 3. Class diagram of the vocabulary learning application

2.3.2 Component Diagram

The component diagram illustrates the structural relationships among the major components of the application. This architecture was designed to ensure modularity, maintainability, and scalability, allowing independent modules to interact through well-defined interfaces. As depicted in Figure 4, the Authentication component manages user login and registration, enabling personalized data retrieval

once users are authenticated. The Vocabulary Manager provides categorized vocabulary lists, which are accessed by the Selection UI component for user interaction. Selected words are then passed to the Game Engine, which governs the execution of both learning games. The Game Engine is integrated with the Hint System to provide limited assistance during gameplay and with the Progress Tracker to record user performance. The Mastered Words component subsequently retrieves data from the Progress Tracker to display vocabulary items that have been successfully learned. This modular design facilitates future system enhancements and ensures smooth data flow across components.

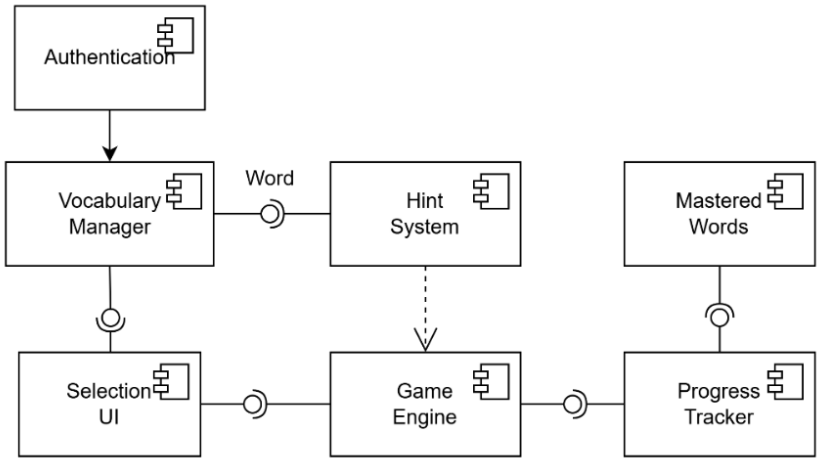


Figure 4. Component diagram of the vocabulary learning application

2.3.3 Activity Diagram

The activity diagram illustrates the sequence of interactions between the user and the application as they complete the vocabulary learning process. As shown in Figure 5, the flow begins when the user opens the application and proceeds with login or registration. Once authenticated, the user navigates to the home page and selects a vocabulary category, followed by choosing a specific word to learn.

The system then directs the user to two main interactive stages: the Word Guess Game and the *Word Match Game*. During the guessing stage, the application checks the correctness of answers and, if necessary, provides hints before allowing the learner to continue. Upon completion, progress is saved, and the user is guided to the matching game, where words must be paired with their corresponding meanings. The system verifies each match and stores successfully learned words in the Mastered Words list.

At the end of the process, successful completion is acknowledged with notifications, while all progress data is stored for future reference. This activity diagram ensures that the entire learning flow is structured, systematic, and consistent, making it easier for users to follow the learning path while ensuring smooth interaction between user actions and system responses.

Additionally, the diagram highlights decision points that allow the system to adapt to individual learner performance. For example, if a user struggles with a particular word in either the *Word Guess* or *Word Match Game*, the system can provide targeted feedback, repeat exercises, or suggest review sessions for difficult words. Gamification elements such as hints, progress bars, mastery counts, and notifications are integrated throughout the flow to enhance learner motivation, engagement, and a sense of achievement. This adaptive mechanism not only reinforces vocabulary retention but also promotes

learner autonomy by enabling personalized learning paths. Furthermore, the structured recording of progress allows instructors or researchers to monitor usage patterns, identify common learning challenges, and refine the application's instructional design, ultimately supporting more effective and engaging technology-enhanced vocabulary learning.

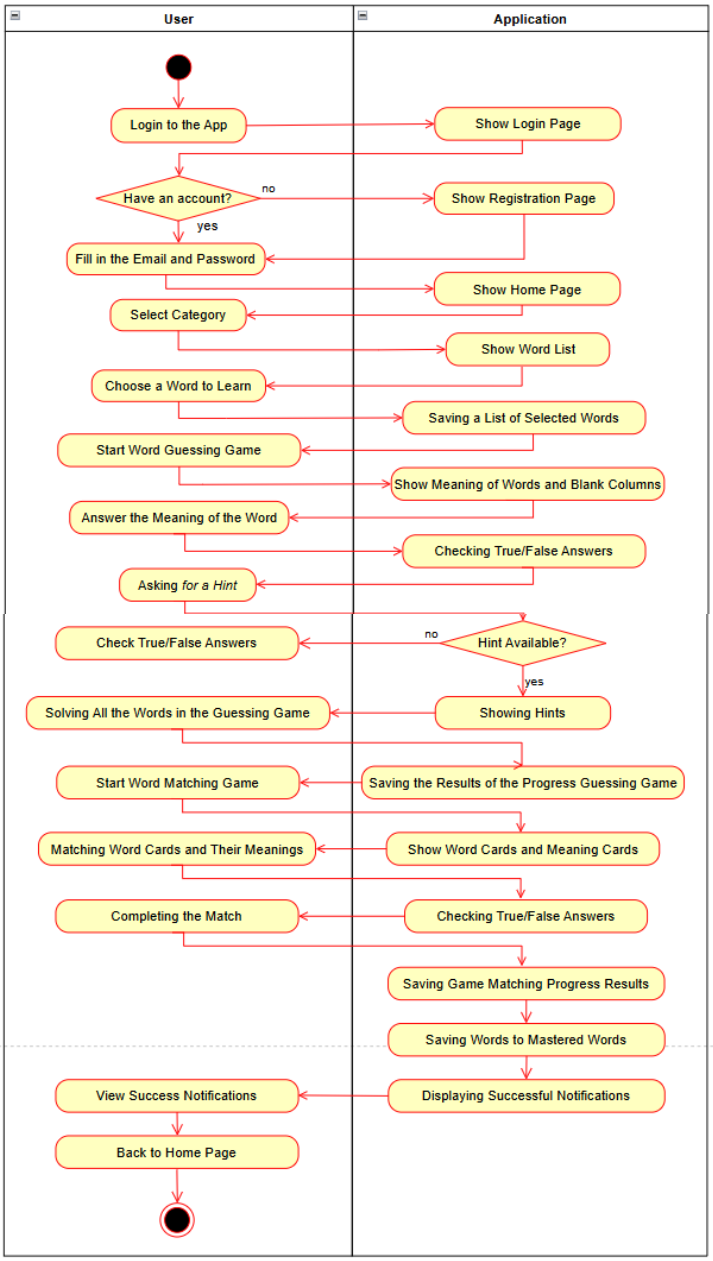


Figure 5. Activity diagram of the vocabulary learning application

2.4 Construction of Prototype

The prototype was implemented using Flutter for the frontend and Firebase for backend services. Flutter was selected for its responsive widget system, efficient rendering engine, and cross-platform capability, enabling consistent deployment across Android and beyond [8]. Meanwhile, Firebase was

chosen to provide secure authentication, cloud-based data storage, and real-time performance monitoring, thus supporting both reliability and scalability [9].

The application was developed using a modular architecture, which promotes maintainability and enables independent updates for each feature. The system integrates six primary modules: (1) the Authentication Module, which manages user login, registration, and personalized data retrieval through Firebase Authentication; (2) the Vocabulary Management Module, responsible for handling categorized vocabulary data sourced from both JSON files and Firebase Firestore; (3) the Word Guess Game Module, which engages learners through interactive letter-based guessing activities equipped with hints and real-time validation; (4) the Word Match Game Module, which facilitates vocabulary–meaning association via drag-and-drop interactions; (5) the Progress Tracking Module, which records user performance and stores mastered words using Firestore and Shared Preferences; and (6) the Performance Monitoring Module, which employs Firebase Performance Monitoring to assess runtime efficiency and identify potential bottlenecks.

Such a modular decomposition aligns with the principles of software modular architecture, which advocate clear module boundaries, high cohesion, and loose coupling to improve maintainability and testability [10], [11]. This modular construction not only supports iterative improvements but also ensures that individual components operate cohesively, contributing to an interactive, robust, and pedagogically aligned learning experience.

2.5 Deployment, Delivery, and Feedback

The final stage, Deployment, Delivery, and Feedback, evaluated both technical performance and pedagogical relevance. The prototype was deployed in real usage contexts, with system responsiveness measured through Firebase Performance Monitoring. Metrics such as login latency, loading time, and game responsiveness were analyzed to ensure efficient operation.

Additionally, expert reviews were conducted by lecturers specializing in English education and educational technology. Their assessments covered usability, design clarity, and pedagogical alignment. Feedback from this stage guided refinements in interface design, game balance, and vocabulary distribution, ensuring that the final product met both technical robustness and educational soundness.

3. RESULTS

The results are presented according to the development stages described in the methodology section. This structure allows a systematic explanation of how the vocabulary learning application was designed, implemented, and iteratively refined based on usability testing and expert feedback.

3.1. Application Development Results

The development phase aimed to produce an interactive, category-based, and game-supported mobile application to enhance the acquisition of technical English vocabulary. The prototype was implemented using Flutter for the front-end interface due to its cross-platform capabilities and efficient UI rendering. Firebase, specifically Firestore, Authentication, and Performance Monitoring, was integrated to provide real-time data management, user authentication, and performance analytics. The finalized application was deployed for Android devices to facilitate accessibility for students.

3.1.1. Login Page Display

The login page, as shown in Figure 6, serves as the entry point to the application by verifying user credentials through Firebase Authentication. It is designed with two input fields: one for the user's email and the other for the password. To improve security and usability, the system incorporates real-time validation that checks the accuracy of input formats and prevents common errors.

Additionally, a show/hide password toggle is provided, allowing users to review their input while maintaining privacy easily. Once the correct credentials are entered, the system grants access and redirects the user to the home page. For new users, a dedicated navigation link is available to guide them to the registration screen. The overall design emphasizes a clean layout, simple navigation, and consistent color schemes, thereby ensuring both functionality and aesthetic appeal in the authentication process.

Figure 6. Login page display

3.1.2. Home Page

The home page, illustrated in Figure 7, serves as the central navigation interface, allowing users to access various learning modules after a successful login. At the top, an AppBar is displayed, containing the application title along with two flag icons—British and Indonesian—that symbolize the bilingual learning support provided by the system. This bilingual feature enables users to seamlessly switch between English and Indonesian seamlessly, facilitating contextual understanding in vocabulary learning.

Beneath the AppBar, four interactive containers are presented. The first directs users to the "Mastered Words" page, allowing them to review vocabulary they have already learned. The remaining three containers grant access to categorized vocabulary modules, specifically General Terms, Tools, and Instructions. This structured layout promotes intuitive navigation, enhances user autonomy, and supports personalized learning experiences tailored to specific areas of interest within the technical domain.

Figure 7. Home page display

3.1.3. Vocabulary Selection Page

The vocabulary selection page (see **Figure 8**) presents a list of words based on the selected category. Users can tap individual word containers to select items, which then change color to yellow and display a check-circle icon on the right side to indicate successful selection. Once the desired vocabulary items are chosen, the "Start Learning" button initiates the Word Guess Game, transitioning users from word selection to active learning engagement.

This interface promotes selective and self-paced learning, aligning with the principles of learner-centered design.

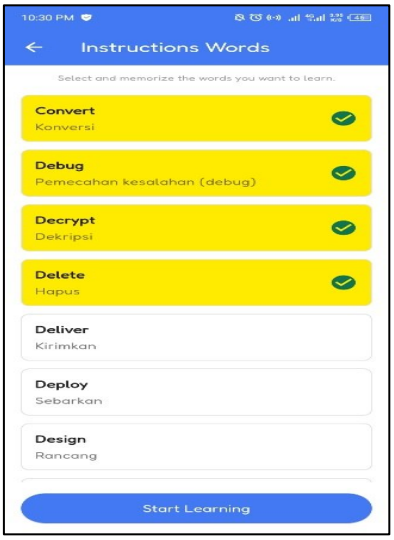
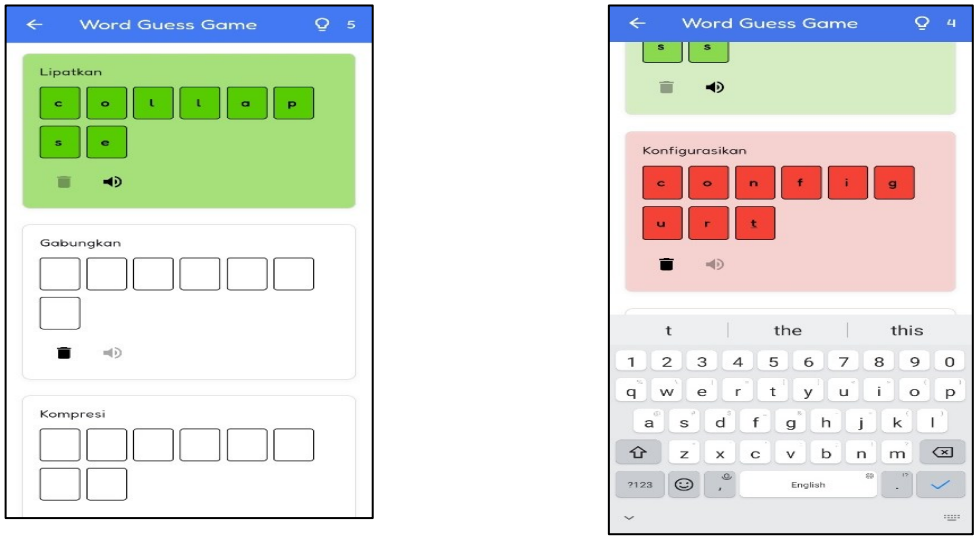


Figure 8. Vocabulary Selection Page Display

3.1.4. Word Guess Game Page

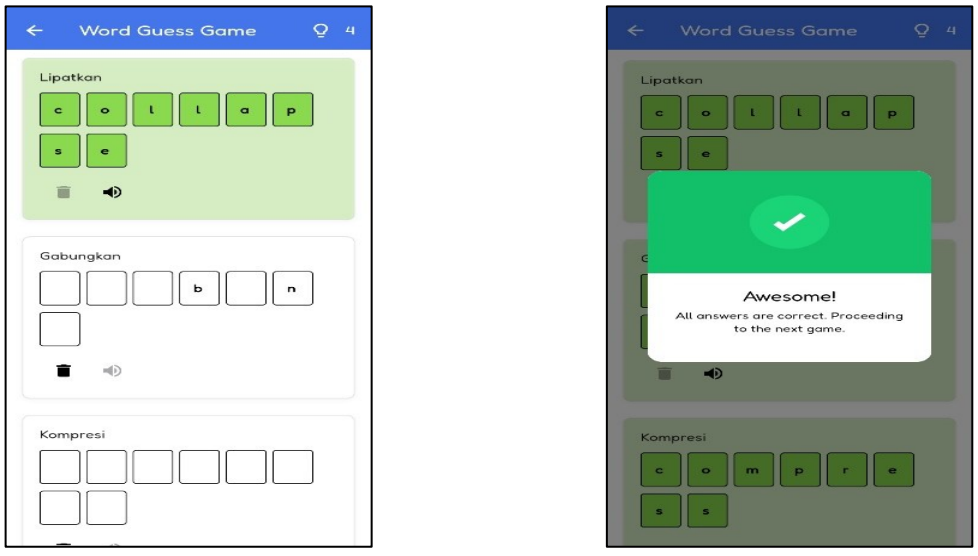
The Word Guess Game, depicted in Figures 9 and 10, engages learners by requiring them to reconstruct English words one letter at a time. Each word is displayed within a container showing its

meaning above input boxes corresponding to the number of letters in the target word. Two control buttons support user interaction: a delete button to reset all input fields and a speaker button (activated upon correct word completion) that triggers text-to-speech (TTS) playback, reinforcing auditory learning. Visual feedback is immediate; correct answers cause the container green for two seconds (Figure 9a), while incorrect responses briefly display a red color (Figure 9b). The hint feature (Figure 10a) provides scaffolding by revealing two random letters per hint, accompanied by confirmation prompts to prevent misuse. Upon completing all items, a success alert appears and automatically redirects users to the next activity (Figure 10b).



(a) (b)

Figure 9. (a) Word Guess Game Correct Display; (b) Word Guess Game Incorrect Display

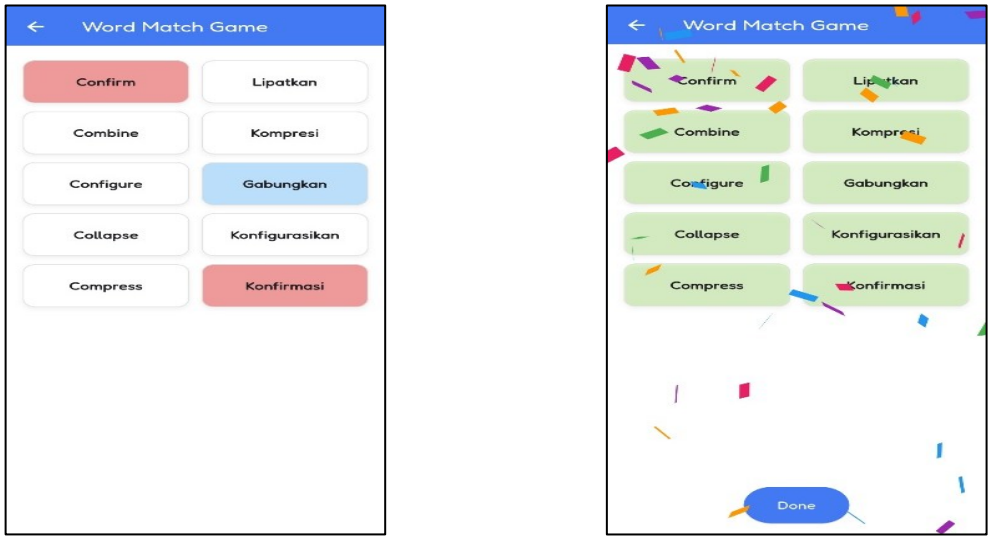


(a) (b)

Figure 10. (a) Word Guess Game Hint Display; (b) Word Guess Game Completion Display

3.1.5. Word Match Game Page

The Word Match Game, illustrated in Figure 11, requires users to pair English words with their corresponding meanings. Each selection changes the card color to blue; incorrect matches highlight the correct pair in red before resetting (Figure 11a), while correct matches turn green and become non-editable (Figure 11b). A celebratory confetti animation is triggered after all pairs are correctly matched, followed by the appearance of a "Done" button that redirects users back to the home page. This gamified feedback mechanism reinforces motivation and consolidates memory through positive reinforcement and repetition, thereby enhancing learning.



(a) (b)

Figure 11. (a) Word Match Game Correct Display; (b) Word Match Game Incorrect Display

3.1.6. Mastered Words Page

After both game stages are completed, all successfully learned vocabulary is automatically stored on the Mastered Words Page, as shown in Figure 12. This feature ensures adaptive learning by removing mastered words from future sessions, allowing learners to focus on vocabulary they have not yet learned. The page displays a list of mastered words with their meanings, serving as a personal learning archive and progress tracker.

Figure 12. Mastered Words Page Display

3.2 Application Testing Results

3.2.1 Performance Testing

Performance testing was conducted using Firebase Performance Monitoring to evaluate the system's responsiveness and efficiency. Custom traces measured critical operations, including app startup, authentication, vocabulary loading, and gameplay responsiveness, as visualized in Figure 13.

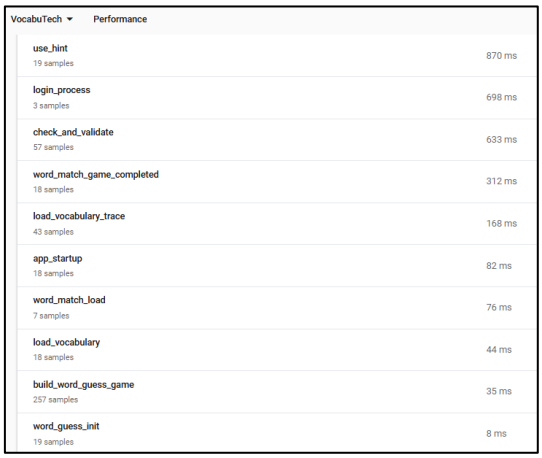


Figure 13. Firebase Performance Monitoring Result

According to Nielsen's usability benchmarks, response times under 0.1 seconds are considered instantaneous, under 1 second are acceptable, and delays over 10 seconds require explicit feedback. The application demonstrated excellent performance, achieving an average startup time of 82 milliseconds. The duration of key operations is summarized in Table 2, with the most efficient processes including word_guess_init (8 ms), build_word_guess_game (35 ms), and load_vocabulary (44 ms).

Table 2. Custom Trace Descriptions

Trace	Duration	Description
word_guess_init	8 ms	Initializes logic for the Word Guess page (shuffle, TTS, input generation).
build_word_guess_game	35 ms	Builds UI for the Word Guess game.
load_vocabulary	44 ms	Loads vocabulary data from local file/service.
word_match_load	76 ms	Prepares Word Match game data.
app_startup	82 ms	Initialization from launch to main UI display.
load_vocabulary_trace	168 ms	Renders vocabulary list on the selection page.
word_match_game_completed	312 ms	Processes game completion and UI feedback.
check_and_validate	633 ms	Validates user answers in the Word Guess game.
login_process	698 ms	Authenticates user credentials via Firebase.
use_hint	870 ms	Executes hint display during gameplay.

More demanding operations, including check_and_validate (633 ms) and use_hint (870 ms), remained well within acceptable performance thresholds, as visualized in Figure 14.

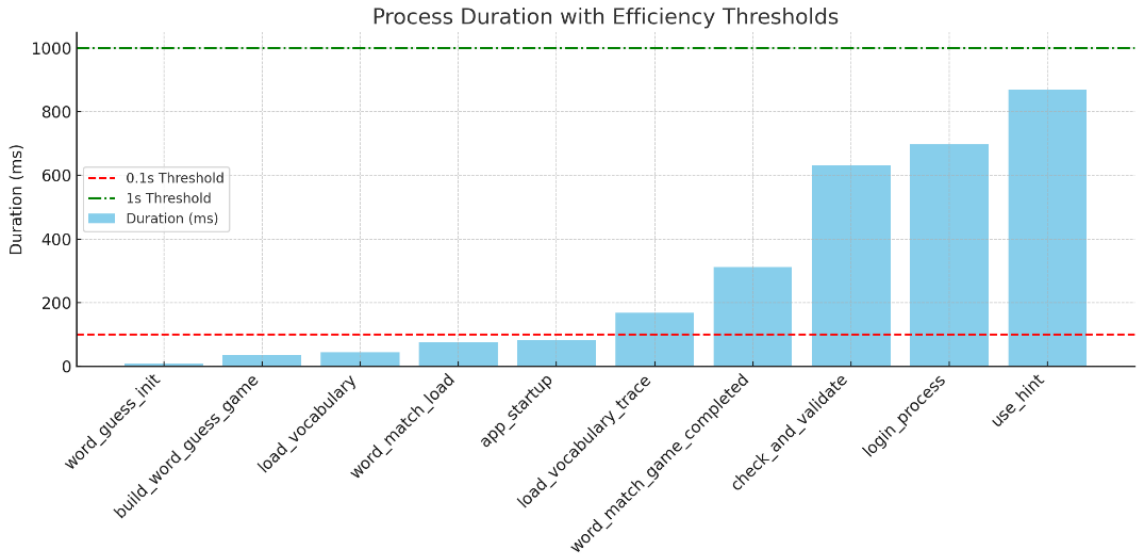


Figure 14. Process Duration with Efficiency Thresholds

UI performance analysis revealed 0% frozen frames throughout user interactions, as depicted in Figure 15, indicating that no frame exceeded the 700 ms rendering threshold. This demonstrates a consistently fluid user experience during navigation, gameplay, and transitions.

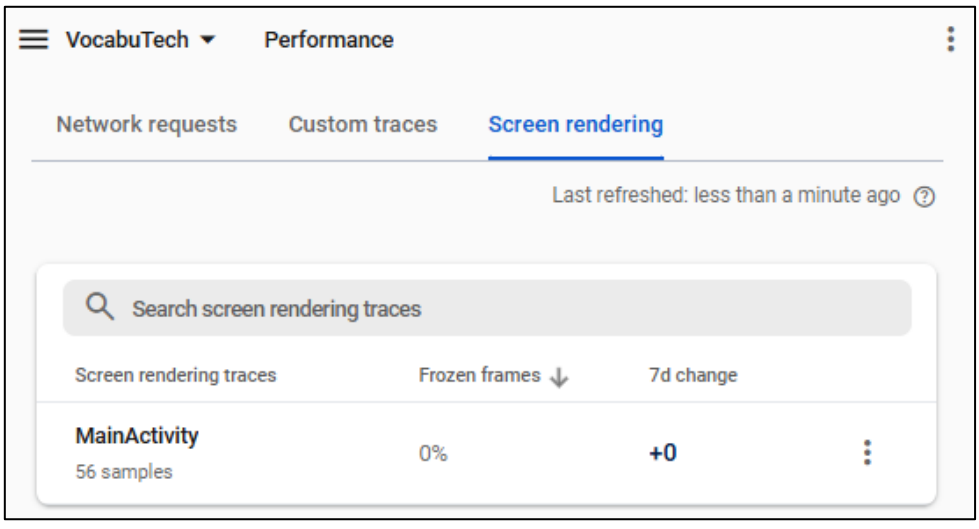


Figure 15. Frozen Frames Result

3.2.2 Expert Review

The final evaluation stage involved an expert review process to ensure the linguistic, pedagogical, and technological validity of the developed vocabulary learning application. Two experts from Universitas Negeri Padang, specializing respectively in English language education and educational technology, participated in this assessment. The expert validation process employed a mixed-method approach combining quantitative scoring and qualitative feedback.

Quantitatively, the experts assessed five significant aspects of the application: content validity, interface design, interactivity, pedagogical appropriateness, and usability, using a 5-point Likert scale that ranged from 1 (*very poor*) to 5 (*excellent*). The evaluation results are summarized in Table 3.

Table 3. Expert Validation Results

Evaluation Aspect	Expert 1	Expert 2	Mean	Category
Content validity	4.6	4.7	4.65	Very valid
Interface design	4.3	4.5	4.4	Valid
Interactivity	4.8	4.7	4.75	Very valid
Pedagogical appropriateness	4.5	4.6	4.55	Very valid
Usability	4.7	4.6	4.65	Very valid
Average Score			**4.6**	**Very valid**

The quantitative results revealed an average validation score of 4.6 out of 5, which falls into the *very valid* category, indicating that the application fulfills the expected quality standards for both instructional media and user experience.

Qualitatively, the experts provided comprehensive feedback on several aspects of improvement. From a linguistic perspective, the English vocabulary and contextual usage were confirmed to be accurate and appropriate for the targeted learners. The experts highlighted that the inclusion of word categories, pronunciation support, and game-based reinforcement effectively promotes language retention and learner engagement.

From a technological and pedagogical standpoint, the reviewers commended the app's interface consistency, smooth navigation, and responsive design enabled by Flutter's framework. They also emphasized the pedagogical alignment between the interactive games (*Word Guess* and *Word Match*) and principles of autonomous vocabulary learning. However, minor revisions were suggested, specifically to improve layout uniformity, clarify the hint function, and balance word frequency across categories. These revisions were implemented in the final prototype to enhance both usability and learning effectiveness.

Overall, the expert review confirmed that the application demonstrates high validity in terms of content accuracy, technical stability, usability, and pedagogical appropriateness. The integration of quantitative and qualitative findings substantiates that the developed application is well-designed for use as a self-directed, gamified mobile learning tool supporting English vocabulary acquisition.

4. Discussion

The present study aimed to develop and validate a mobile application for learning technical English vocabulary through gamified activities—Word Guess and Word Match—using Flutter as the development framework and Firebase as the backend infrastructure. The findings demonstrated that the application met both technical and pedagogical quality standards. The Firebase Performance Monitoring analysis confirmed that the system maintained stable runtime performance with minimal latency during authentication, data retrieval, and gameplay interactions. Concurrently, expert evaluations yielded a mean validity score of 4.6 out of 5, categorized as *very valid*, indicating that the application's content,

usability, and design are consistent with the principles of effective instructional media and digital learning environments [12], [13].

These results reinforce existing literature emphasizing that mobile-assisted language learning (MALL) applications can significantly improve learner engagement and vocabulary retention when interactivity and gamification elements are well integrated [14], [15]. The integration of real-time feedback, text-to-speech functionality, and progress visualization supports theories of autonomous learning and self-regulated vocabulary acquisition [16]. This is consistent with Deci and Ryan's Self-Determination Theory (SDT), which highlights autonomy, competence, and relatedness as core motivators in sustained learning engagement [17]. By offering learners control over their progress and providing immediate feedback on performance, the application strengthens intrinsic motivation and promotes long-term vocabulary mastery.

The pedagogical design of the application also aligns with the constructivist paradigm and the Cognitive Theory of Multimedia Learning (CTML). Through the combination of text, sound, and interactive visual components, learners engage in dual-channel processing that facilitates deeper semantic encoding and improved recall [18]. The Word Guess and Word Match modules exemplify how multimodal learning can support meaningful interaction with content, moving learners beyond passive exposure toward active, experiential vocabulary construction. Moreover, the inclusion of challenge-based elements such as limited hints, incremental feedback, and progressive task complexity aligns with gamified learning models that emphasize engagement through immediate reinforcement and achievable goals [19], [20], [21]. Similar effects have been observed in studies demonstrating that gamification and augmented reality (AR) enhance engagement, motivation, and performance in educational contexts [22], [24], [25].

When compared to previous mobile vocabulary learning applications, the proposed system demonstrates both technological and pedagogical innovation. Many prior MALL systems have primarily targeted general English proficiency [14], while this study contributes specifically to technical English instruction within engineering contexts—a domain where students often encounter challenges due to specialized terminology [26]. Technologically, the use of Flutter ensures cross-platform compatibility and consistent user experience across devices, addressing limitations found in applications developed solely for native Android or iOS platforms [27]. The integration of Firebase Cloud Firestore further enhances functionality by enabling real-time data management and secure synchronization, promoting scalability and persistent data tracking across learning sessions [28]. These innovations demonstrate that effective mobile learning design requires both pedagogical soundness and robust system architecture.

From a practical perspective, the developed application offers meaningful implications for English language educators, instructional designers, and software developers. For educators, the application can serve as a supplementary tool in English for Specific Purposes (ESP) courses, particularly in technical and engineering disciplines [26]. Its modular structure allows for flexible integration into blended or flipped classroom models, supporting autonomous and self-paced learning beyond formal instruction [29]. For developers and instructional technologists, the study presents a replicable model for integrating Flutter and Firebase ecosystems in educational technology development [27], [28]. The incorporation of Firebase Performance Monitoring exemplifies a data-driven approach to continuous improvement, ensuring that learning applications remain both pedagogically relevant and technically optimized [12].

Nevertheless, several limitations must be acknowledged. The validation process involved only two expert reviewers, which constrains the generalizability of the findings. Future studies should involve a larger and more diverse group of evaluators, including both educators and learners, to capture multidimensional perspectives on usability, accessibility, and learning impact [13]. Moreover, while performance testing

confirmed technical stability, the study did not empirically assess learning outcomes such as vocabulary gain, retention rate, or learner motivation. Subsequent research should employ experimental or quasi-experimental designs to measure the application's effectiveness in improving learning outcomes and engagement [24], [25]. In addition, integrating adaptive learning algorithms based on artificial intelligence could enhance personalization by adjusting vocabulary sequences or difficulty levels in response to learner performance data [30], [31]. Cross-linguistic validation across cultural and educational contexts is also recommended to examine the generalizability of the system's design principles [14], [28].

Theoretically, this study contributes to the growing body of knowledge in technology-enhanced learning (TEL) by demonstrating how the prototyping method can function as a structured, iterative framework that bridges the gap between instructional design theory and technical implementation [32]. The results empirically affirm that gamified, mobile-based learning environments can enhance learner engagement and autonomy by integrating real-time feedback, interactivity, and progress visualization [19], [20]. Furthermore, the combination of Flutter and Firebase provides a technically robust yet pedagogically grounded model for future educational software development, particularly in contexts that require scalability, rapid prototyping, and continuous performance evaluation [27], [28].

Overall, the findings suggest that the developed application effectively integrates educational theory and technological design to create an engaging, efficient, and pedagogically sound learning tool for acquiring technical English vocabulary. Beyond its immediate context, this research offers a methodological and conceptual framework for developing future mobile learning innovations that emphasize both learner experience and system performance. Such convergence between software engineering and educational theory not only supports sustainable digital learning design but also advances interdisciplinary research within the broader field of educational technology [22], [30].

5. CONCLUSION

This study demonstrates the feasibility of integrating mobile technology and gamified design to support vocabulary learning in technical English contexts. Through a structured prototyping approach, the application evolved into a pedagogically grounded and technically reliable tool that aligns with the principles of learner autonomy, engagement, and contextualized language practice. The research contributes to the broader field of technology-enhanced language learning by exemplifying how the synergy between software engineering frameworks (Flutter and Firebase) and instructional design can generate scalable, data-driven educational solutions. It also highlights the importance of modular architecture and real-time monitoring as foundational elements for sustaining performance and user experience in educational applications. From a pedagogical perspective, the developed system extends current practices in English for Specific Purposes (ESP) by embedding adaptive, self-directed, and gamified mechanisms that foster motivation and retention beyond the classroom. In this regard, the study underscores a paradigm shift from content delivery toward active, learner-centered engagement mediated by technology. Future work should move beyond expert validation toward empirical testing with learners to evaluate measurable learning outcomes, engagement levels, and long-term vocabulary retention. Expanding the system's adaptability through artificial intelligence, particularly in personalized feedback and vocabulary recommendation, represents a promising trajectory for subsequent development. In essence, this study provides a methodological and conceptual blueprint for future innovation at the intersection of mobile learning, gamification, and language education, reaffirming that meaningful digital pedagogy requires the seamless integration of technological precision and instructional purpose.

DECLARATIONS

Author Contributions

Anita Nursi: Conceptualization, Methodology, Software Development (Flutter), Investigation, Writing – Original Draft, Writing – Review & Editing. **Resmi Darni:** Supervision, Validation, Formal Analysis, Evaluation of Pedagogical Soundness, Writing – Review & Editing. **Dony Novaliendry:** Supervision, Validation, Data Curation (Firebase integration), Empirical Evaluation, Writing – Review & Editing. All authors have read and approved the final version of this manuscript.

Acknowledgments

The authors would like to thank all individuals, institutions, and external collaborators who contributed their expertise and support during the design, development, and evaluation of the mobile application.

Ethical Approval

This study involved human participants only in the form of expert review for evaluating the mobile application. All experts provided informed consent before participation.

Funding

The authors declare that this research received no external funding. All aspects of the study, including app development (using Flutter and Firebase), gamification design, and expert validation, were conducted independently without financial support from any organization.

Competing Interests

The authors declare that they have no conflicts of interest.

Generative AI and AI-Assisted Technologies Statement

During the preparation of this manuscript, the authors utilized ChatGPT-4o and Grammarly to improve clarity, readability, and coherence. ChatGPT-4o assisted in refining explanations related to instructional design, gamification, and empirical evaluation, while Grammarly helped identify and correct grammar, punctuation, and style issues. All content, interpretations, and conclusions were independently verified and manually edited by the authors.

REFERENCES

[1] R. Fithriani, "The Utilization of Mobile-assisted Gamification for Vocabulary Learning: Its Efficacy and Perceived Benefits," *Computer-Assisted Language Learning Electronic Journal*, vol. 22, no. 3, pp. 146–163, 2024. [Online]. Available: https://callej.org/index.php/journal/article/view/357

[2] Y. Lai, N. Saab, and W. Admiraal, "University students' use of mobile technology in self-directed language learning: Using the integrative model of behavior prediction," *Computers & Education*, vol. 179, p. 104413, Apr. 2022, doi: 10.1016/j.compedu.2021.104413.

[3] Z. J. Zhang, "Exploring the effects of different gamified learning conditions on L2 learners' vocabulary acquisition using Quizlet," in *Proc. Int. CALL Research Conf.*, 2024, pp. 339–344, doi: 10.29140/9780648184485-51.

[4] B. Maraza-Quispe *et al.*, "Impact of the Use of Gamified Online Tools: A Study with Kahoot and Quizizz in the Educational Context," *Int. J. Inf. Educ. Technol.*, vol. 14, no. 1, pp. 132–140, 2024, doi: 10.18178/ijiet.2024.14.1.2033.

[5] I. Maryani *et al.*, "Gamified Mobile-Based Learning Approach: Efforts to Improve Students' Engagement and Learning Quality in Remote Schools in Indonesia," *Educational Process: International Journal*, vol. 15, e2025179, Apr. 2025, doi: 10.22521/edupij.2025.15.179.

[6] E. Bjarnason, F. Lang, and A. Mjöberg, "An empirically based model of software prototyping: A mapping study and a multi-case study," *Empirical Software Engineering*, vol. 28, no. 115, 2023, doi: 10.1007/s10664-023-10331-w.

[7] B. Kang, N. Crilly, W. Ning, and P. O. Kristensson, "Prototyping to elicit user requirements for product development: Using head-mounted augmented reality when designing interactive devices," *Design Studies*, vol. 84, p. 101147, 2023, doi: 10.1016/j.destud.2022.101147.

[8] "Flutter architectural overview," *Flutter Documentation*. [Online]. Available: https://docs.flutter.dev/resources/architectural-overview

[9] "Creating beautiful mobile applications using Flutter and Firebase," *Google Developer Forum Discussion*, 2022.

[10] D. Mryrr, "A Modular Software Architecture for Embedded Systems," *IFAC Proc. Vol.*, vol. 39, no. 21, pp. 101–105, Feb. 2006, doi: 10.1016/S1474-6670(17)30166-0.

[11] M. Shortt, S. Tilak, I. Kuznetcova, B. Martens, and B. Akinkuolie, "Gamification in mobile-assisted language learning: A systematic review of Duolingo literature from public release of 2012 to early 2020," *Computer Assisted Language Learning*, vol. 36, no. 3, pp. 517–554, 2023, doi: 10.1080/09588221.2021.1933540.

[12] H. Puspitasari, R. F. Maharani, W. H. Setyawan, and Y. Primasari, "Android-based mobile application for vocabulary learning," *Jurnal Pendidikan dan Pembelajaran (JPP)*, vol. 55, no. 3, pp. 469–479, Dec. 2022, doi: 10.23887/jpp.v55i3.40661.

[13] M. D. Gall, J. P. Gall, and W. R. Borg, Educational Research: An Introduction, 8th ed. Boston, MA, USA: Pearson, 2007.

[14] M. 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. doi: 10.1017/S0958344008000335.

[15] G. Rangel-de Lazaro and J. M. Duart, "Moving learning: A systematic review of mobile learning applications for online higher education," *Journal of New Approaches in Educational Research*, vol. 12, pp. 198–224, 2023, doi: 10.7821/naer.2023.7.1287.

[16] P. Gou, "Teaching English using mobile applications to improve academic performance and language proficiency of college students," *Education and Information Technologies*, vol. 28, pp. 16935–16949, 2023, doi: 10.1007/s10639-023-11864-9.

[17] R. M. Ryan and E. L. Deci, "Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions," *Contemporary Educational Psychology*, vol. 61, p. 101860, 2020, doi: 10.1016/j.cedpsych.2020.101860.

[18] R. E. Mayer, Multimedia Learning, 3rd ed. Cambridge, UK: Cambridge University Press, 2021. doi: 10.1017/9781108894333.

[19] S. Deterding, D. Dixon, R. Khaled, and L. Nacke, "From game design elements to gamefulness: Defining 'gamification'," in Proc. 15th Int. Acad. MindTrek Conf., 2011, pp. 9–15. doi: 10.1145/2181037.2181040.

[20] K. M. Kapp, The Gamification of Learning and Instruction: Game-Based Methods and Strategies

for Training and Education. San Francisco, CA, USA: Pfeiffer, 2012.

[21] A. Hamari, J. Koivisto, and H. Sarsa, "Does gamification work?—A literature review of empirical studies on gamification," in Proc. 47th Hawaii Int. Conf. Syst. Sci., 2014, pp. 3025–3034. doi: 10.1109/HICSS.2014.377.

[22] S. Tzima, G. Styliaras, and A. Bassounas, "Augmented reality applications in education: Teachers point of view," *Education Sciences*, vol. 9, no. 2, art. no. 99, 2019, doi: 10.3390/educsci9020099.

[23] H.-Y. Chang, T. Binali, J.-C. Liang, G.-L. Chiou, K.-H. Cheng, S. W.-Y. Lee, and C.-C. Tsai, "Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact," *Computers & Education*, vol. 191, p. 104641, Dec. 2022, doi: 10.1016/j.compedu.2022.104641.

[24] Y. Tiantian, A. B. Razali, N. N. Zulkifli, and J. J. Jeyaraj, "The effects of collaborative mobile learning approach on academic performance: The mediating role of social interaction, and learning motivation," *Journal of Pedagogical Research*, vol. 8, no. 3, pp. 209–229, 2024, doi: 10.33902/JPR.202426264.

[25] R. Teymouri, "Recent developments in mobile-assisted vocabulary learning: A mini review of published studies focusing on digital flashcards," *Frontiers in Education*, vol. 9, art. no. 1496578, 2024, doi: 10.3389/feduc.2024.1496578.

[26] T. Dudley-Evans and M. St. John, Developments in English for Specific Purposes: A Multi-Disciplinary Approach. Cambridge, UK: Cambridge University Press, 1998.

[27] K. Kishore, S. Khare, V. Uniyal and S. Verma, "Performance and stability Comparison of React and Flutter: Cross-platform Application Development," *2022 International Conference on Cyber Resilience (ICCR)*, Dubai, United Arab Emirates, 2022, pp. 1-4, doi: 10.1109/ICCR56254.2022.9996039.

[28] R. Mallik, A. P. Hazarika, S. Ghosh Dastidar, et al., "Development of an Android application for viewing Covid-19 containment zones and monitoring violators who are trespassing into it using Firebase and geofencing," *Transactions of the Indian National Academy of Engineering*, vol. 5, pp. 163–179, 2020, doi: 10.1007/s41403-020-00137-3.

[29] C. Garrison and H. Kanuka, "Blended learning: Uncovering its transformative potential in higher education," The Internet and Higher Education, vol. 7, no. 2, pp. 95–105, 2004. doi: 10.1016/j.iheduc.2004.02.001.

[30] M. C. Laupichler, A. Aster, and T. Raupach, "Delphi study for the development and preliminary validation of an item set for the assessment of non-experts' AI literacy," *Computers and Education: Artificial Intelligence*, vol. 4, p. 100126, 2023. doi: 10.1016/j.caeai.2023.100126.

[31] M. Holmes, A. Bialik, and C. Fadel, Artificial Intelligence in Education: Promises and Implications for Teaching and Learning. Boston, MA, USA: Center for Curriculum Redesign, 2019.

[32] R. Pressman and B. Maxim, Software Engineering: A Practitioner's Approach, 9th ed. New York, NY, USA: McGraw-Hill Education, 2020.

AUTHOR BIOGRAPHIES

Anita Nursi is a bachelor's student in the Informatics Study Program at Universitas Negeri Padang, Indonesia. She is interested in developing mobile applications for education, with a focus on gamified and self-directed learning tools that support the acquisition of technical vocabulary in engineering contexts. Her work emphasizes the integration of instructional design principles with technology to enhance learner engagement and autonomy, particularly in engineering education.

Resmi Darni is a faculty member at the Faculty of Engineering, Universitas Negeri Padang (UNP), Indonesia. Her expertise lies in educational technology, information systems development, and digital learning media, including augmented reality (AR) applications in education. She is actively involved in research and community service projects, such as AI-based career information systems for vocational students, AR-based learning media for physical education courses, and digital cooperative systems in collaboration with local community initiatives.

Dony Novaliendry is a faculty member at the Faculty of Engineering, Universitas Negeri Padang (UNP), Indonesia. His research interests include artificial intelligence, machine learning, data mining, image processing, and technology-enhanced learning. He is actively involved in the development of educational applications and international research collaborations.