

Original Article

Design and Implementation of an AI-Based Korean Pronunciation Learning System with Personalized Feedback

Hyojung Jung¹, Heejeung Jee², Hyunmi Do³, Hyeji Kim^{4*}, Sangmin Woo⁵

¹ Assistant Professor, College of Innovation and Convergence, Dankook University, Korea (hyojung.jung@dankook.ac.kr)

² Research Professor, Department of Bio-health Convergence, Dankook University, Korea (jane.jee@dankook.ac.kr)

³ Research Professor, Department of Bio-health Convergence, Dankook University, Korea (edutech80@dankook.ac.kr)

⁴ Bachelor of Engineering, Department of Software Science, Dankook University, Korea (32201293@dankook.ac.kr)

⁵ Bachelor of Engineering, Department of Software Science, Dankook University, Korea (32192713@dankook.ac.kr)

*Corresponding Author : 32201293@dankook.ac.kr

ABSTRACT

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Objectives: The demand for Korean language learning has increased with global interest in Korean culture. However, non-native speakers struggle with pronunciation due to Korean's unique phonological features. This study aims to develop an AI-based pronunciation evaluation application to provide structured and personalized feedback. **Methods:** The system uses a client-server architecture, integrating an Android app, a FastAPI server, and an SQLite database. The AI model evaluates pronunciation based on accuracy, fluency, and completeness, and checks keyword usage in learners' spoken responses. **Results:** A pilot study with non-native Korean learners showed high user satisfaction with the system's learning content and feedback quality. **Conclusions:** The AI-based application effectively supports Korean pronunciation learning by offering real-time, structured feedback. Pilot results suggest strong potential for broader application in Korean language education.

Keywords: AI-based learning, FastAPI, non-native learners, Korean pronunciation evaluation, Pronunciation error analysis

1. Introduction

1.1. Necessity of the Study

With the global spread of K-culture, interest in learning the Korean language has dramatically surged. As the number of global learners aiming to consume Korean cultural products such as K-pop, K-dramas, and K-films continues to grow, Korean is no longer merely a language but a global tool with cultural and economic value. However, Korean language learners face various challenges during the learning process, and pronunciation acquisition remains one of the most significant hurdles. Korean is charac-

terized by a unique phonological system, including final consonants, diphthongs, tense consonants, and phonological rules that distinguish it from other languages. Non-native speakers often struggle to master these features, which not only hampers their phonological accuracy but also negatively affects their communication skills, motivation, and confidence [1].

The existing Korean pronunciation teaching materials and educational systems have failed to adequately address these challenges. An analysis of Korean pronunciation textbooks performed by Lee (2012) identified a lack of clear selection criteria for pronunciation topics and insufficient structural coherence. Furthermore, these textbooks often

focus on theoretical explanations instead of practical exercises, limiting learners' opportunities to systematically practice and correct pronunciation. The absence of personalized pronunciation instruction tailored to learners' native language backgrounds is another critical issue that has failed to meet the needs of diverse linguistic groups. This indicates a lack of systematic approaches in the current pronunciation education systems, highlighting the urgent need for effective pronunciation learning tools.

In addition to phonological challenges, psychological factors related to pronunciation learning pose significant challenges. According to Wei (2023), Chinese learners of Korean as a foreign language (KFL) report high levels of anxiety during pronunciation evaluation processes, such as the speaking section of the TOPIK test. This anxiety stems from various factors, including unfamiliarity with the test environment, lack of interaction, and adaptation issues with computer-based evaluation formats. In particular, when learners are not well-informed about the evaluation procedures and question types, their anxiety levels escalate, undermining their motivation and performance. Therefore, designing systems that alleviate the psychological burden and provide a stable learning environment is crucial.

Recent advancements in artificial intelligence (AI) technology offer promising possibilities for addressing these issues using pronunciation learning tools. Ji (2022) demonstrated that cross-lingual learning methodologies using wav2vec 2.0 can overcome data scarcity and enhance the accuracy of pronunciation error detection. Unlike conventional approaches that require extensive non-native speaker data for model training, cross-lingual learning leverages the phonological features of both the learners' native language and the target language, thereby reducing data collection costs while maintaining high performance. This AI-based approach has the potential to precisely analyze pronunciation errors among learners with diverse linguistic backgrounds and provide data-driven feedback to effectively improve their pronunciation skills.

Furthermore, existing studies have emphasized the importance of segmenting pronunciation error types and adopting data-driven analysis. For instance, common pronunciation errors among Korean learners include phoneme substitutions, deletions, and insertions that are closely related to their native language characteristics [1, 5]. Systematically analyzing these errors and incorporating the learners' linguistic backgrounds into feedback systems can significantly enhance the quality of Korean language education.

Thus, a growing need for digital tools that address both the phonological and psychological challenges of pronunciation learning has emerged, enabling learners to acquire

Korean pronunciation effectively. This study aims to design and implement an AI-based Korean pronunciation evaluation application that systematically analyzes learners' pronunciation errors and provides personalized feedback that reflects both data-driven and psychological factors. Accordingly, it seeks to establish a new standard for Korean language learning, thereby alleviating the difficulties learners face in pronunciation acquisition and promoting the digital transformation and globalization of Korean language education.

1.2. Research Questions

This study aims to design and implement an application that provides an effective pronunciation learning experience for Korean language learners. To achieve this, the following research questions are proposed:

First, how can systematic Korean pronunciation learning content be designed by incorporating progressive learning stages, such as word-, sentence-, and keyword-based tasks?

Second, how can an AI-based system be implemented to evaluate learners' pronunciation with accuracy and objectivity?

Third, how can a user-friendly interface be developed to visually deliver pronunciation feedback and enhance learning effectiveness?

2. Literature Review

2.1. Necessity of AI-Based Korean Pronunciation Assessment and Previous Studies

The Korean language has a phonological system that differs from other languages, particularly in aspects such as final consonant pronunciation and vowel length distinction, which pose challenges to pronunciation acquisition [2-8, 12]. Foreign language learners typically practice pronunciation using audio files from textbooks or receive feedback from instructors; however, it is difficult to instantly analyze and correct individual pronunciation errors. Traditional pronunciation learning methods are often unidirectional (audio-based learning), making it difficult for learners to recognize and improve their pronunciation problems independently [3].

Yoon (2022) analyzed the Korean pronunciation and learning strategies used by foreign undergraduate students majoring in Korean language education and explored pronunciation teaching directions for prospective foreign Korean language instructors [9]. The study revealed that prospective Korean language teachers tended to prefer repetitive practice and learning over specific strategies for

pronunciation improvement. Among pronunciation learning strategies, cognitive strategies are the most frequently used, whereas metacognitive strategies are relatively underutilized. Additionally, the study revealed that learners preferred correcting pronunciation errors in natural conversational situations rather than relying on direct feedback from instructors.

Given that traditional Korean pronunciation education depends heavily on instructor feedback, this study highlights the need for an educational approach that encourages learners to acquire and apply pronunciation strategies independently. In particular, this suggests that pronunciation instruction should focus more on practice-oriented methods that reflect natural intonation and speech contexts.

Yu (2013) analyzed the content and methods of pronunciation education in Korean language textbooks to propose effective pronunciation teaching strategies [10]. The findings indicate that current Korean language textbooks primarily follow a communicative teaching approach but often fail to systematically address pronunciation education. Most textbooks provide only brief pronunciation guidelines at the beginner level, with little to no structured pronunciation instruction in later stages. In addition, pronunciation education is largely based on instructors providing pronunciation models and learners mimicking recorded materials, making it structurally challenging for learners to correct their pronunciation effectively or acquire pronunciation skills systematically.

These findings suggest that the AI-based pronunciation assessment system developed in this study can serve as an alternative tool for providing structured and continuous pronunciation feedback. In particular, it should be designed to offer reinforced feedback on phonological variation rules and suprasegmental features (intonation and stress), as well as level-based personalized pronunciation support. Furthermore, moving beyond traditional repetitive practices, a personalized feedback system with pronunciation error analysis can emerge as a more effective learning strategy.

Accordingly, AI-based pronunciation assessment systems have garnered attention as novel alternatives. However, previous studies have lacked sufficient discussion on how optimized AI-based pronunciation assessment models are constructed for Korean language learners. In addition, most existing AI pronunciation assessment systems have been developed primarily for English pronunciation learning, with relatively limited studies on AI systems for Korean pronunciation evaluation. This study aims to analyze the design and implementation of AI-based pronunciation assessment systems tailored to Korean learners and explore solutions to overcome the limitations identified in previous studies.

2.2. AI Technology in Language Learning and Pronunciation Assessment

Advancements in AI technology have led to significant changes to language learning methodologies, particularly in the fields of speech recognition (speech-to-text) and natural language processing, which are garnering attention in language education systems [7, 11]. AI has the advantages of analyzing speech data, evaluating learners' pronunciation, and providing real-time feedback. Recent studies have demonstrated that AI-based pronunciation assessment systems effectively enhance learners' pronunciation accuracy. In particular, AI-powered language learning applications such as Duolingo and ELSA Speak incorporate pronunciation assessment features to provide learners with real-time feedback, and studies have reported that these methods yield higher learning effectiveness compared with traditional pronunciation education. Although previous speech recognition technologies were primarily based on phoneme-level analysis, recent applications of deep learning and machine learning models have enabled more sophisticated pronunciation assessments [5].

Shim (2022) analyzed the current status and challenges of Korean pronunciation learning using speech recognition technology (SRT) and identified the limitations of existing pronunciation learning applications while proposing directions for improvement [3]. The study discovered that current Korean pronunciation learning applications primarily provide pronunciation accuracy scores or feedback through intonation graph comparisons with native speakers. However, these applications have structural limitations that make it difficult for learners to understand their pronunciation errors intuitively.

Additionally, although SRT-based Korean pronunciation assessment contributes toward improving learners' comprehensibility, existing assessment methods that focus on comparisons with native pronunciation are often overly strict or inconsistent in feedback. This suggests the need to complement traditional score-based evaluations by visually presenting speech recognition results and allowing learners to analyze and correct their errors independently. Furthermore, rather than merely offering score-based feedback, learners should be provided with detailed explanations to help them clearly identify and correct their pronunciation errors.

Most existing studies have primarily focused on discussing ways to improve pronunciation education but have fallen short in proposing concrete alternative technologies and learning methods that can be applied in practice. First, current Korean pronunciation education studies have not sufficiently considered AI-based assessment systems that provide personalized feedback to learners.

Second, existing studies lack a strategic approach to pronunciation error analysis and pronunciation improvement, with an insufficient discussion on differentiated assessment methods that consider learners' proficiency levels and learning contexts. Third, studies on improving the reliability of speech recognition-based pronunciation assessment systems and enhancing the specificity of feedback remains inadequate, particularly when addressing the issue of AI assessment models assigning overly lenient or excessively strict scores, which necessitates a data-driven approach for improvement.

Therefore, this study seeks to overcome the limitations of previous studies and empirically examine the application of AI-based pronunciation assessment systems in actual Korean learning environments. Specifically, it aims to address the limitations identified in pronunciation education studies by utilizing AI technology to explore more sophisticated pronunciation analysis and feedback provision methods. Moreover, this study focused on developing a personalized pronunciation assessment system that reflects learners' proficiency levels and learning patterns. Additionally, to improve the reliability of AI-based pronunciation evaluation, this study analyzes pronunciation error types in greater detail and explores the potential for refining evaluation algorithms based on learner feedback, ultimately proposing a direction for enhancing the effectiveness of AI-powered pronunciation education.

3. Research Methods

This study adopts a structured methodology to design and implement an AI-based Korean pronunciation evaluation application. The research process follows a sequential approach that encompasses various phases to ensure effective development, evaluation, and refinement of the system.

The initial phase involves designing the overall application architecture based on a client-server model. The client application was developed using Android, and the server employed FastAPI to handle pronunciation evaluation requests. The server processes user inputs, analyzes pronunciation using an AI model, and returns the evaluation results. To support efficient learning content management, an SQLite database is embedded within the client application, allowing the structured storage and retrieval of essential learning materials.

Following the architectural design, the database development phase focuses on organizing the learning content systematically. The database contains metadata related to learning topics, structured into chapters and stages, along with corresponding text data, including words, sen-

tences, and keywords. In addition, it stores the paths to audio files and recorded speech data. The database was designed to dynamically retrieve relevant content based on user selection using SQL queries to facilitate seamless content access.

The next phase centers on the development of the AI-based pronunciation evaluation model. This model, integrated into the FastAPI server, quantitatively assesses pronunciation by generating scores within a defined range. It evaluates pronunciation accuracy, fluency, and completeness, and offers detailed feedback beyond a simple numerical score. In the advanced learning stages, the model also analyzes whether learners incorporate essential keywords into their spoken responses and incorporates this aspect into the scoring process to ensure a more comprehensive pronunciation assessment.

To ensure usability and accessibility, the user interface (UI) design and implementation phases focus on creating an intuitive and engaging learning experience. The application provides interactive screens for content selection, pronunciation recording, and feedback evaluation. The text-to-speech (TTS) feature allows users to listen to model pronunciations before recording their own speech. Evaluation results are categorized into different levels, visually represented through pop-up messages that encourage progress, including motivational prompts such as "Excellent," "Try Again," and "Needs Improvement."

Before deployment, system integration and testing were performed to optimize client-server communication and validate system performance. This phase assessed the response times for pronunciation evaluation requests, accuracy of audio file processing, and consistency of the evaluation results across different learning stages. Additionally, error-handling mechanisms were tested to ensure that system stability was maintained under various conditions.

The pilot testing phase involved non-native Korean learners evaluating the usability of the system's. Participants assessed the usefulness of the learning content, reliability of the pronunciation evaluation results, and intuitiveness of the UI. The feedback collected during this phase provides valuable insights for refining the application, helping to enhance both system functionality and user experience.

By adopting this structured development approach, this study aimed to create a highly functional AI-driven pronunciation evaluation system that enhances Korean language learning. Through the integration of AI technology and user-centered design principles, this study contributes to the advancement of Korean language education by offering a precise, interactive, and learner-adaptive digital tool.

4. Application Development

4.1. Application Architecture

The application was designed using a client-server architecture, in which the Android-based client communicates with a FastAPI-based server to process pronunciation evaluation requests. When users initiate pronunciation evaluation, the server analyzes the recorded speech using an AI model specialized for pronunciation assessment and returns the results.

To manage the learning content efficiently, the application embeds an SQLite database within the client. This database organizes essential information, including content details, such as words, sentences, and keywords, as well as the corresponding recording and audio file names. By structuring the database in this manner, the application ensures the seamless retrieval of learning materials and smooth interaction between the content and pronunciation evaluation processes.

When users begin their learning sessions, they select their preferred topic and proceed through a structured progression of the chapters and learning stages. Based on their selection, the system retrieves relevant learning content through database queries. Throughout the learning process, the users engage in pronunciation exercises and

receive AI-generated feedback. Upon completion of the learning stage, the system provides a comprehensive evaluation summary that offers insights into the user's overall performance and pronunciation progress.

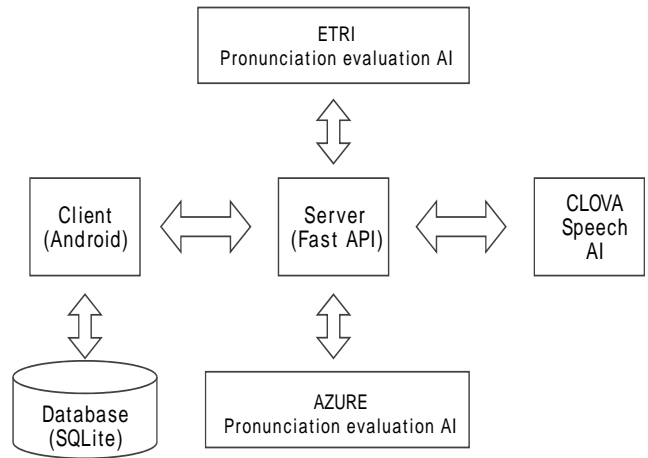


Fig. 1. System architecture

4.2. Application Services

The application provides Korean language learning through various topics, including contemporary Korean culture, local cuisine, campus life, medical visits, regional tourism, and job interview preparations. Each topic com-

Table 1. Database (Sample)

id	topic	chapter	step_num	text_idx	sentenceA
1	Campus life	chapter1	1	1,0,0	University, School
11	Campus life	chapter1	2	1,1,1	I love campus
21	Campus life	chapter1	3	1,1,1	Campus, Love it

audiofile_str	recordfile_str	sentenceQ	sub_topic	keyword_idx
1_0_0_audio.mp3	/1_0_0_record	-	-	-
1_1_1_audio.mp3	/1_1_1_record	How is our campus?	First impression of Campus	-
1_1_0_audio.mp3	/1_1_1_record	How is our campus?	First impression of Campus	1,1

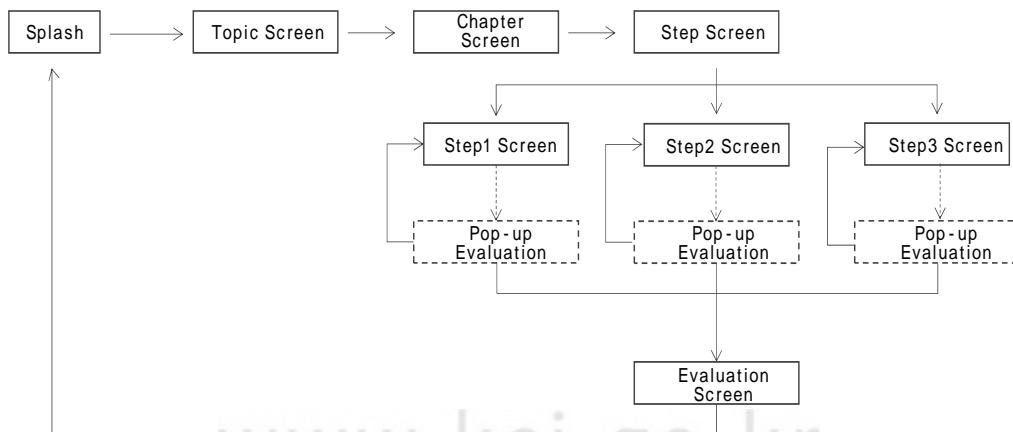


Fig. 2. Screen layout

prises multiple chapters with a structured learning process that follows a gradual progression.

The learning stages begin with basic pronunciation drills in which users practice repeating words. As they advance, they proceed to sentence-based exercises that offer contextualized learning experiences. In the most advanced stage, users are required to respond to questions by incorporating specific keywords into their answers, reinforcing their ability to construct meaningful and accurate spoken responses.

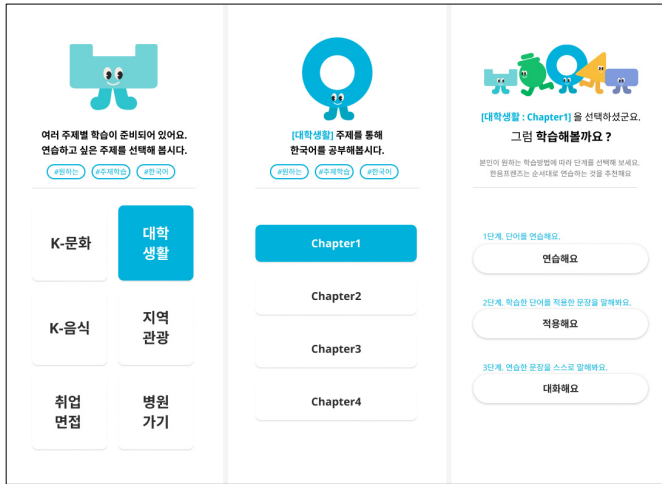


Fig. 3. Topics, chapters, and learning stages screen

To facilitate pronunciation practice, the system allows users to listen to model pronunciations by pressing a speaker button that generates audio using AI-driven text-to-speech technology. The users then record their pronunciation using a microphone button, and the system captures their speech through a media recorder. Once recorded, the application processes a pronunciation evaluation request by sending a recorded file to the server for analysis.

During the evaluation process, a loading screen appears to indicate that the pronunciation assessment is in progress. If the system encounters an issue, such as an unsuccessful API request or an unrecognizable audio input, an error



Fig. 4. Stages 1, 2, and 3 learning screens



Fig. 5. Evaluation loading popup and error toast messages

message is displayed to notify the user. This functionality ensures a smooth user experience while maintaining clarity in the feedback process.

The pronunciation evaluation system assesses user speech by assigning a performance rating based on pronunciation accuracy. The feedback was categorized into three distinct levels to help users understand their progress. The highest category signified strong pronunciation proficiency, the intermediate category indicated the need for further practice, and the lowest category highlighted areas requiring significant improvement.

For the word- and sentence-based pronunciation exercises, users received an overall score that reflected their pronunciation accuracy. For keyword-based responses, the evaluation also included feedback on pronunciation clarity and keyword inclusion. If a required keyword was missing from the spoken response, the system identified omission and assigned an appropriate score.

Table 2. Evaluation Score Ranges

Stage	Level 1 (Excellent)	Level 2 (Try Again)	Level 3 (Needs Improvement)
Stage 1	0-40	40-55	55-100
Stage 2	0-40	40-70	70-100
Stage 3	0-40	40-70	70-100

Upon completing all the learning content, users gain access to a detailed summary of their progress. For basic pronunciation practice, the summary includes individual word evaluations and overall pronunciation scores. For sentence- and response-based exercises, the summary provides a more detailed analysis, including overall performance ratings, evaluations of fluency and completeness, and recognized sentences, along with their pronunciation scores.

By providing a structured feedback system, the application enables learners to identify areas for improvement

and track their progress over time. The integration of AI-powered pronunciation evaluation within a structured learning process enhances language acquisition by offering learners an interactive and personalized approach to improve their spoken Korean. Through this adaptive methodology, the application supports a more effective pronunciation learning experience.



Fig. 6. Score screen

5. Research Results

The AI-based Korean pronunciation evaluation application developed in this study successfully provided a structured learning experience with precise feedback tailored to non-native Korean learners. The research findings are categorized into three main areas: implementation of the system, accuracy of the AI-driven pronunciation evaluation, and validation of the user experience. Each of these aspects contributes toward understanding the effectiveness and practical applications of the developed system.

5.1. System Implementation Outcomes

The system was designed using a client-server structure to ensure seamless communication between the Android-based client and the FastAPI server. The client-side application incorporated an SQLite database to manage and retrieve learning content efficiently, offering users a diverse range of study materials. The content included practical themes, such as Korean pop culture, university life, and job interviews, allowing learners to engage in contextualized pronunciation practice.

Within the application, users progressed through different learning stages, including word-, sentence-, and keyword-based exercises. The system supported fully functional audio recording and pronunciation evaluation, ensuring that learners received immediate feedback on their

spoken Korean. One of the key technical achievements of the implementation was the real-time processing capability. The API requests for pronunciation evaluation were executed with an average response time of approximately 2 s, making the system suitable for real-time feedback without causing noticeable delays.

5.2. AI Pronunciation Evaluation Accuracy

The pronunciation evaluation model was designed to assess the users' spoken Korean using a quantitative scoring system ranging from 0 to 100. To provide a more detailed analysis of pronunciation proficiency, the system incorporated three key evaluation metrics: accuracy, fluency, and completeness. These metrics allowed learners to identify specific areas for improvement rather than relying solely on an overall pronunciation score.

The results of the pilot test confirmed that the AI-based pronunciation evaluation system maintained a high level of accuracy, with an overall evaluation reliability of 92.5%. Additionally, the keyword detection feature demonstrated an accuracy rate exceeding 90%, ensuring that the learners' spoken inputs were correctly recognized and assessed. The feedback was structured into three performance categories: "Excellent," "Try Again," and "Needs Improvement," which allowed users to gauge their progress effectively and remain motivated to improve their pronunciation skills.

5.3. User Validation Results

To evaluate the user experience and effectiveness of the application, a pilot test was performed with 30 non-native Korean learners representing different levels of proficiency. The user validation process focused on three key aspects: the perceived usefulness of the learning content, reliability of pronunciation evaluation, and overall user experience (UI/UX) satisfaction.

The results revealed that 93% of participants deemed the learning content engaging and practically beneficial, particularly appreciating the contextualized approach that allowed them to practice pronunciation in real-life scenarios. Regarding the reliability of the AI-based pronunciation evaluation system, 90% of users expressed confidence in the accuracy of the assessments and found the detailed feedback metrics useful for tracking their progress. In addition, 87% of participants rated the UI as intuitive and convenient, highlighting the effectiveness of visual feedback and motivational pop-up messages provided at different learning stages. These elements played crucial roles in maintaining engagement and encouraging continued practice.

Despite the positive reception, some participants sug-

gested that more explicit pronunciation correction guidance should be integrated into the system. Specifically, they recommended the inclusion of visual or audio-based comparisons that demonstrate correct pronunciation alongside learners' mispronounced words or phonemes. Furthermore, several users noted that background noise and low-quality recordings occasionally affected the accuracy of pronunciation assessments, emphasizing the need for improved signal processing and noise reduction algorithms to ensure more precise evaluation results.

Overall, these findings suggest that an AI-based pronunciation evaluation system can be an effective tool for enhancing Korean language learning experiences. By addressing the areas identified for improvement, this application has the potential to significantly contribute to the advancement of Korean language education on a global scale.

These findings highlight several pedagogical advantages over traditional pronunciation learning methods. Unlike conventional approaches that provide static audio samples and lack personalized correction, this system enables immediate, targeted feedback through AI analysis. Furthermore, by incorporating fluency and completeness—rather than focusing solely on accuracy—the model offers a more holistic assessment of learners' speaking proficiency. This comprehensive approach is better suited to promoting communicative competence and learner autonomy in Korean language education.

6. Conclusion and Recommendations

6.1. Conclusion

This study developed and implemented an AI-based pronunciation evaluation application aimed at providing a systematic and effective learning experience for non-native Korean learners. Although previous studies have predominantly focused on traditional pronunciation instruction reliant on teacher feedback and textbook-based audio materials, this study sought to bridge this gap by integrating AI-driven personalized pronunciation assessment into Korean language education.

Unlike previous studies that primarily analyzed the limitations of one-way pronunciation learning methods (e.g., audio-based imitation without interactive feedback), this study introduced an interactive AI model that provides real-time, quantitative pronunciation analysis based on accuracy, fluency, and completeness scores. In addition, existing AI-based pronunciation assessment applications, such as Duolingo and ELSA Speak, have been designed primarily for English learners, limiting their application to Korean pronunciation learning. This study addressed this gap by

developing an AI system specifically optimized for Korean phonological characteristics, including final consonants, vowel length distinctions, and unique phonetic rules.

Through empirical testing, the application demonstrated high user satisfaction in terms of content reliability, system usability, and motivation for continuous learning. These findings indicate that AI-driven pronunciation assessment can serve as a practical tool for Korean language learners, offering structured, data-driven feedback that enhances autonomous learning. Moreover, by complementing existing pronunciation education approaches, this study contributes to the digital transformation and personalization of Korean language learning experiences.

However, although the application successfully provided an innovative approach to pronunciation evaluation, certain limitations remained, particularly regarding the generalizability of the AI model across diverse linguistic backgrounds and the need for a more granular feedback system. Given these challenges, the study proposes further refinements to enhance pronunciation accuracy analysis, learner adaptation mechanisms, and pedagogical applicability, as discussed in the following recommendations.

In future studies, the effectiveness of the AI-based system should be validated through controlled comparative experiments. Specifically, a control group using conventional methods (e.g., instructor feedback or audio repetition practice) should be compared against a treatment group using the AI system. Outcome variables may include pronunciation accuracy improvement, error awareness, and learner motivation. Such comparative designs will offer more rigorous empirical evidence of the system's educational impact and substantiate its advantages in real-world instructional settings.

6.2. Limitations and Future Directions

Although this study successfully developed an AI-based pronunciation evaluation system for Korean learners and demonstrated its potential through a pilot test, certain limitations should be acknowledged. Addressing these limitations is crucial to refine the system and expand its applicability to a broader population of learners.

One major limitation is the relatively small sample size of the pilot test, which included only 30 participants. Although the results provided valuable insights into the system's usability, reliability, and learning effectiveness, a larger-scale study involving a more diverse group of learners would enhance the generalizability of the findings. Future studies should include participants with varying proficiency levels, linguistic backgrounds, and exposure to Korean language learning environments to better assess the adaptability and effectiveness of the system.

Another limitation lies in the scope of error analysis within the pronunciation evaluation system. Although the AI model effectively identified pronunciation accuracy, fluency, and completeness, a more detailed error classification system could further enhance the learning outcomes. Conducting an in-depth analysis of common pronunciation errors by learner group and integrating more precise phoneme-level feedback would improve the ability of the system to provide actionable guidance. In addition, a comparative analysis with existing AI pronunciation tools and traditional instruction methods would strengthen the contextual grounding of the study by highlighting how the system advances beyond current approaches.

Scalability and adaptability are areas of further refinement. The current model, which is effective for controlled pilot testing, has not yet been tested on a larger scale with diverse linguistic variations. Learners from different native language backgrounds may exhibit distinct pronunciation challenges, and the AI model must be trained on a more comprehensive dataset to accommodate regional accents, dialectal variations, and phonetic influences. Developing an adaptive scoring mechanism that dynamically adjusts the evaluation criteria based on the learner's native language and proficiency level would enhance the fairness and effectiveness of the system.

Technical improvements are required to ensure greater reliability and real-world usability. The accuracy of pronunciation evaluation is occasionally affected by background noise and recording inconsistencies, particularly in environments in which learners may not have access to high-quality audio input. Future enhancements should focus on signal processing optimizations, noise reduction techniques, and audio enhancement algorithms to minimize external interference and improve recognition precision.

Finally, the integration of additional learning modalities can further enrich the capabilities of a system. While the current model focuses on pronunciation assessment, incorporating interactive role-playing scenarios, real-time AI conversation practice, and multimodal feedback combining text, speech, and visuals, would provide a more holistic approach to language learning. Developing a web-based platform would further increase accessibility, allowing users to engage with the system across multiple devices while integrating social learning features and collaborative feedback mechanisms.

By addressing these limitations and expanding the scope of the study, future developments can enhance the scalability, adaptability, and pedagogical effectiveness of AI-based pronunciation evaluation. This study serves as an important step in advancing AI-driven language learning tools and lays the foundation for more inclusive, inter-

active, and personalized Korean language education in the digital age.

Author Contributions

Conceptualization: Hyojung Jung
 Visualization (Designed the in-app feedback visualization components for learners): Heejeung Jee
 Software (Developed the Android application and implemented the user interface): Hyeji Kim
 Data Curation, Validation: Sangmin Woo
 Data collection, Formal analysis: Hyunmi Do
 Writing-original draft: Hyojung Jung
 Writing-review & editing: Hyunmi Do

ORCID

Hyojung Jung: <https://orcid.org/0000-0001-5046-5007>
 Heejeung Jee: <https://orcid.org/0000-0001-7638-2621>
 Hyunmi Do: <https://orcid.org/0009-0000-5657-7384>
 Hyeji Kim: <https://orcid.org/0009-0001-8375-7636>
 Sangmin Woo: <https://orcid.org/0009-0009-4962-4475>

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Conflicts of Interest

No author has any other conflict of interest to declare.

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