24-25J-233.pdf

by Umesha Silva

Submission date: 11-Apr-2025 11:35PM (UTC+0530)
Submission ID: 2607904880
File name: 24-25J-233.pdf (1.06M)
Word count: 18227
Character count: 124285

LEXAYUDHA : PERSONALIZED AI-DRIVEN REHABILITATION FOR ADOLESCENTS WITH DYSLEXIA AND DYSCALCULIA

24-25J-233

BSc (Hons) degree in Information Technology Specializing in Software Engineering

Department of Computer Science & Software Engineering

Sri Lanka Institute of Information Technology
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Dissertation submitted in partial fulfillment of the requirements for the Bachelor of Science (Hons) in Information Technology Specializing in Software Engineering

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DECLARATION

We declare that this is our own work, and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.
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Abstract

LexAyudha is an innovative, AI-powered personalized learning platform designed to address the multifaceted challenges faced by adolescents with learning disabilities such as dyslexia and dyscalculia. These conditions often result in difficulties with reading fluency, comprehension, speech processing, and emotional regulation, which traditional educational tools fail to adequately support due to their lack of adaptability and personalization. LexAyudha integrates advanced technologies to provide a holistic solution that caters to both cognitive and emotional needs.

The platform incorporates a Chromatic Variation-Based Teaching Module , which uses chromatic adjustments to reduce visual stress, dynamically generates sentences tailored to individual reading levels via a fine-tuned BERT model and provides real-time pronunciation feedback through a Text-to-Speech (TTS) module. Additionally, LexAyudha employs emotion-aware adaptive learning by leveraging a customized Xception-based Convolutional Neural Network (CNN) for real-time facial emotion detection. This allows the system to identify states such as frustration, engagement, or distraction, enabling it to modify task difficulty dynamically and create an emotionally responsive learning environment.

Furthermore, LexAyudha enhances speech comprehension for neurodiverse learners using a hybrid Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN) model. By analyzing mel spectrogram images derived from speech audio data, the system predicts optimal speech pace tailored to individual needs, delivering customized audio output via Google TTS. For dyscalculic learners, the platform also introduces a gamified, multisensory web-based application based on the Touch Math method, designed to improve number sense and mathematical operations through interactive and engaging activities.

Pilot evaluations across diverse school settings demonstrate significant improvements in reading accuracy, reduced visual stress, enhanced speech comprehension, increased learner engagement, and better emotional regulation. Educators and guardians have positively rated the platform's usability, accessibility, and impact. By combining AI-driven personalization, affective computing, and multisensory teaching methods, LexAyudha exemplifies a transformative approach to inclusive education. Future enhancements, including multilingual support and expanded accessibility features, are recommended to further broaden its applicability and impact in diverse educational contexts.

Keywords: *chromatic variation, dyscalculia, dyslexia, emotion detection, mel spectrogram, touch math*

Acknowledgement

We are grateful to all those who contributed to the successful completion of this project, which has been a truly collaborative effort. First and foremost, we extend our heartfelt thanks to our supervisor, Prof. Samantha Thelijjagoda, our co-supervisor, Dr. Junius Anjana, and our external supervisor, Dr. Asiri Hewamalage, for their invaluable guidance, constructive feedback, and unwavering support throughout this research journey. Their expertise and mentorship were instrumental in shaping the direction, quality, and success of this project.

We are also immensely thankful to Mrs. G. Nadeeka Priyangani Rupasinghe, Principal of R/Raththurugala Vidyalaya, Ratnapura, for her generous assistance in facilitating access to students for data collection and usability testing. Her cooperation enabled us to rigorously evaluate the system in real-world settings, significantly enhancing its reliability, credibility, and impact.

Special acknowledgment goes to our fellow team members, whose dedication, collaboration, creativity, and innovative ideas were pivotal in bringing this project to fruition. Their commitment, late-night brainstorming sessions, and problem-solving energy kept us moving forward with a shared vision. We also extend our gratitude to our peers, colleagues, and the students who participated in the usability tests and supported the data collection, testing, and troubleshooting phases.

On a personal note, we are incredibly grateful to our families for their constant encouragement, emotional support, and understanding throughout this journey. Their belief in us has been a source of strength and motivation.

This project would not have been possible without the collective efforts of these individuals and organizations, and we are genuinely appreciative of the contributions and support received from everyone involved.

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
AI	Artificial Intelligence
CNN	Convolutional Neural Networks
MTCNN	Multi-Task Cascaded Convolutional Networks
NLP	Natural Language Processing
RNN	Recurrent Neural Network
TTS	Text to Speech

1. INTRODUCTION

Learning disabilities such as dyslexia and dyscalculia are prevalent among adolescents worldwide, significantly impacting their academic performance, social development, and emotional well-being. Dyslexia, characterized by difficulties in reading and writing, affects approximately 19% of students with learning disabilities in the United States [1], while in Sri Lanka, over 3,500 students from grades 1 to 11 were reported to have dyslexia in 2019[2] (see Appendix A, Figure1, 2). Similarly, dyscalculia presents challenges in understanding and manipulating numbers, hindering mathematical learning. Despite the availability of assistive tools, many traditional educational interventions fail to address the unique needs of these learners due to their lack of real-time personalization and adaptability. This generalized approach often leads to frustration, disengagement, and diminished self-esteem among neurodiverse students.

The emotional dimension of learning is equally critical, as students with dyslexia and dyscalculia frequently experience heightened stress levels up to 20–30% higher than their peers during learning activities [3]. Emotional states such as frustration, distraction, and anxiety can exacerbate learning difficulties, underscoring the need for emotionally responsive educational environments. Recent advancements in artificial intelligence (AI) and affective computing offer transformative opportunities to bridge these gaps by creating adaptive, emotion-aware learning platforms.

LexAyudha is an innovative, AI-powered platform designed to address the cognitive and emotional challenges faced by adolescents with dyslexia and dyscalculia. The platform integrates multiple cutting-edge technologies to deliver personalized learning experiences. One of its core components is the Chromatic Variation-Based Teaching Module , which combines adaptive sentence generation, real-time chromatic adjustments, and Text-to-Speech (TTS) feedback to enhance reading fluency and comprehension. Additionally, LexAyudha leverages facial expression recognition through CNN-based models (e.g., Xception) to detect emotion classes such as frustration, engagement, and distraction, dynamically adjusting task difficulty to optimize learning outcomes.

The platform also incorporates a Personalized Speech Pace Module , which utilizes a hybrid Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN) model to analyze mel spectrogram representations of speech audio. This module predicts optimal speech pace tailored to individual needs, delivering customized audio output via Google Text-to-Speech (TTS) to improve speech comprehension. Furthermore, LexAyudha provides guardians with personalized emotional feedback reports, fostering collaboration between home and school environments to support learners holistically.

By addressing both cognitive and emotional dimensions of learning, LexAyudha exemplifies a transformative approach to inclusive education. The following sections delve into the theoretical foundations, research gaps, and objectives that guide the development of this platform, highlighting its potential to revolutionize learning experiences for neurodiverse adolescents.

1.1 Background Literature

Learning disabilities such as dyslexia and dyscalculia are among the most prevalent challenges faced by adolescents worldwide, significantly impacting their academic performance, social development, and emotional well-being. Dyslexia, characterized by difficulties in reading, writing, and comprehending written and spoken language, affects approximately 20% of the global population [1]. Dyscalculia, on the other hand, impairs an individual's ability to understand numbers and perform arithmetic operations, affecting 3-6% of the population globally [2]. These conditions not only hinder academic success but also lead to heightened stress levels up to 20–30% higher than their peers during learning activities [3]. Despite the availability of assistive tools, traditional educational interventions often fail to address the unique cognitive, sensory, and emotional needs of neurodiverse learners [4].

The integration of artificial intelligence (AI) and advanced technologies into education offers transformative opportunities to bridge these gaps. LexAyudha is an innovative, AI-driven platform designed to address the multifaceted challenges faced by adolescents with dyslexia and dyscalculia. By combining chromatic variation, emotion-aware adaptability, personalized speech pace adjustments, and multisensory teaching methods, LexAyudha creates a holistic and inclusive learning environment tailored to individual needs [5], [6]. The following sections delve into the theoretical foundations, research gaps, and technological innovations that underpin this groundbreaking platform [7].

1.1.1 Chromatic Variation and Visual Accessibility

Visual stress is a common issue among dyslexic readers, often manifesting as distorted or blurred text when engaging with traditional black-on-white content. This condition hampers fluency, comprehension, and overall engagement. Research has shown that specific chromatic combinations, such as pale-yellow text on a dark blue background, can significantly reduce visual stress and enhance word recognition accuracy [8]. Table 1.1 illustrates recommended chromatic pairings based on their effectiveness for dyslexic readers.

Table 1.1: Recommended chromatic pairings

Text Color	Background Color	Effectiveness
Pale Yellow	Dark Blue	High
Black	White	Moderate
Green	Pale Yellow	High

These findings align with guidelines from organizations like the British Dyslexia Association, which advocate for personalized color schemes, appropriate font choices, and optimized contrast [9]. However, despite proven effectiveness, most digital platforms still rely on static visual settings, leaving many dyslexic learners without the support they need [10].

To address this gap, LexAyudha incorporates a Chromatic Variation-Based Teaching Module that dynamically adjusts color schemes, font sizes, and contrast levels in real time based on individual visual comfort. Leveraging AI, the module ensures that learning materials remain accessible and engaging, reducing visual stress while enhancing readability and comprehension. This approach represents a significant advancement over existing systems, which often overlook the sensory challenges faced by dyslexic students [11].

1.1.2 Emotion Detection and Adaptive Learning

Emotion detection has emerged as a pivotal area of research in modern education, particularly for designing adaptive learning environments tailored to individual needs. Adolescents with dyslexia and dyscalculia frequently experience elevated stress levels during academic activities, leading to frustration, disengagement, and reduced self-esteem [12], [13]. Traditional educational approaches fail to address these emotional challenges, exacerbating learning difficulties [14].

Paul Ekman's theory of basic emotions provides a foundational framework for facial expression recognition, identifying six universally recognized emotions: happiness, sadness, anger, fear, surprise, and disgust [15]. While fear and disgust are less relevant in learning contexts, emotions like frustration, distraction, and engagement are critical for understanding student performance [16]. Facial expression recognition systems leveraging deep learning models, such as Convolutional Neural Networks (CNNs) and Xception-based models, have demonstrated high accuracy in classifying these emotions in real time [17], [18].

LexAyudha integrates emotion-aware adaptability through its Facial Expression Recognition Module , which uses Multi-Task Cascaded Convolutional Networks (MTCNN) for face detection and Xception models for emotion classification [19], [20]. Detected emotions are used to dynamically adjust task difficulty, ensuring that students remain engaged and motivated. Additionally, the platform provides guardians with personalized emotional feedback reports via a cloud-based dashboard, fostering collaboration between home and school environments [21].

Despite advancements in affective computing, specialized systems for students with dyslexia and dyscalculia remain scarce. LexAyudha bridges this gap by tailoring its emotion detection algorithms to the unique emotional profiles of neurodiverse learners, offering a transformative model for inclusive and empathetic digital education [22].

1.1.3 Personalized Speech Pace Adjustment

Adolescents with dyslexia often struggle to process spoken language at typical conversational speeds, leading to difficulties in understanding verbal instructions and engaging effectively in learning activities [23]. While existing tools like Speechify and TextAid offer adjustable speech rates, they lack the sophistication required to deliver truly personalized speech pace adjustments based on individual characteristics [24].
Recent advancements in deep learning, particularly hybrid Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), have demonstrated exceptional capabilities in analyzing complex audio signals and mel spectrogram images [25]. LexAyudha leverages these technologies in its Personalized Speech Pace Module , which processes spoken responses to predict optimal speech pace tailored to individual needs. The system converts audio into mel spectrograms using libraries like Librosa, analyzes temporal and spatial features with a hybrid CNN-RNN model, and delivers customized audio output via Google Text-to-Speech (TTS) [26], [27].
This approach ensures that dyslexic learners receive content at a pace that aligns with their unique comprehension abilities, reducing cognitive load and fostering inclusivity. By integrating cutting-edge AI methodologies with user-centered design principles, LexAyudha addresses a critical gap in the current technological landscape [28], [29].

1.1.4 Multisensory Learning for Dyscalculia

Traditional interventions for dyscalculia have relied on single-sensory teaching methods, targeting visual, auditory, or kinesthetic learning channels independently [30]. However, these approaches are insufficient to address the complex needs of students with dyscalculia. Multisensory techniques, such as the Touch Math method, have proven highly effective in enhancing engagement and retention of mathematical concepts [31], [32].
Despite its efficacy, the application of Touch Math has largely been confined to physical, in-person teaching environments, leaving a significant gap in the digital landscape. Existing platforms often lack interactivity, personalization, and real-time

feedback mechanisms, which are critical for addressing the unique learning needs of students with dyscalculia [33], [34].
LexAyudha bridges this gap by integrating the principles of multisensory learning with advanced AI technologies. The platform's gamified, web-based implementation of Touch Math combines tactile, visual, and auditory stimuli to teach numerical concepts dynamically [35], [36]. By incorporating speech recognition and natural language processing (NLP), LexAyudha ensures a truly personalized and engaging learning experience [37], [38]. This approach exemplifies how technology can transform educational tools for students with dyscalculia, making them more accessible and impactful.

While considerable progress has been made in areas such as chromatic research, emotion detection, and personalized learning, few educational systems holistically integrate these elements to support neurodiverse learners in real time [39]. LexAyudha represents a pioneering approach that bridges cognitive, emotional, and sensory gaps in learning by embedding chromatic variation, intelligent adaptation, language simplification, and multisensory teaching into a cohesive, personalized educational platform [40].
By leveraging AI-driven methodologies and user-centered design principles, LexAyudha exemplifies how technology can revolutionize learning experiences for individuals with dyslexia and dyscalculia. This convergence marks a significant step toward equitable, inclusive, and responsive education for all learners. Future enhancements, including multilingual support and expanded accessibility features, are recommended to further increase the platform's impact across diverse educational contexts.

1.2 Research Gap

Despite significant advancements in educational technology, several critical gaps remain in addressing the unique needs of adolescents with dyslexia and dyscalculia. These gaps underscore the necessity for innovative, AI-driven solutions that can provide personalized, adaptive, and inclusive learning experiences.

1.2.1 Chromatic Variation and Visual Accessibility

Chromatic variations have long been recognized for their potential to improve reading performance among individuals with dyslexia. Visual stress characterized by blurred, distorted, or unstable text commonly affects dyslexic readers, often leading to cognitive fatigue and reduced reading fluency. Research confirms that strategic changes to text and background color, such as pale-yellow text on dark blue backgrounds, significantly reduce visual stress and enhance word recognition [5]. However, the practical implementation of chromatic variation in educational technologies remains limited. Most existing tools rely on static configurations or basic user-driven customization, offering fixed color schemes without responsiveness to a learner's individual challenges or evolving needs. These one-size-fits-all models fail to capture the heterogeneity of dyslexic symptoms and neglect the fact that optimal visual settings may vary not only between learners but also for the same learner over time.

A critical gap in current systems is the absence of real-time feedback mechanisms that adapt both visual presentation and content difficulty dynamically. While adaptive systems like ALEKS and other Intelligent Tutoring Systems (ITS) have demonstrated the potential of AI to personalize learning trajectories based on cognitive performance, they rarely address sensory challenges such as visual discomfort experienced by dyslexic learners. Existing applications like ALEXZA illustrate how AI and ML can enhance learning outcomes by tailoring tasks based on performance, but these systems largely emphasize auditory and cognitive aspects of learning without incorporating real-time visual personalization. Integrating AI-powered chromatic adaptation into such frameworks could provide a holistic solution that dynamically adjusts to the learner's evolving visual and cognitive profile.

Additionally, while Natural Language Processing (NLP) tools simplify complex sentences and restructure paragraphs to make content more accessible linguistically, they often ignore the visual aspects of reading. This disjointed approach limits the effectiveness of personalized learning for dyslexic students. LexAyudha addresses this gap by proposing a web-based platform that uses AI to personalize both the content and the modality of reading material, ensuring a seamless blend of linguistic simplification and visual adaptation.

1.2.2 Emotion Detection and Personalized Feedback

Emotion detection technologies have gained traction in educational settings, particularly for enhancing learning outcomes through adaptive systems. However, there remains a notable lack of research focused on providing personalized feedback to guardians regarding the emotional states of students with dyslexia and dyscalculia during learning activities. While existing systems excel at detecting emotions, they often fail to translate this data into actionable insights for parents and educators. This gap limits the ability of guardians to intervene effectively when students exhibit signs of frustration or disengagement, which is especially critical for students with learning disabilities who require tailored support.

Another significant gap lies in the inadequate dynamic adjustment of learning activities based on detected emotions. Many current systems do not prioritize modifying task difficulty in response to the emotional state of the student. For students with dyslexia and dyscalculia, who often experience heightened levels of stress and frustration, this adaptability is essential to maintaining engagement and reducing cognitive overload. Additionally, most existing emotion detection systems rely on generalized emotional baselines that may not accurately reflect the emotional responses of students with learning disabilities. These generalized models can misclassify emotions or fail to recognize subtle emotional cues specific to dyslexic and dyscalculic students.

The integration of multimodal approaches such as combining facial expressions, voice analysis, and physiological signals remains underexplored in the context of learning disabilities. Such integration could offer a more comprehensive understanding of students' emotional states, improving the quality of support provided. Cultural and dataset bias further complicates the application of emotion detection technologies, as many models are trained on datasets lacking cultural diversity, leading to biased results. Addressing these gaps is crucial for creating inclusive systems that cater to the global demographic of students with learning disabilities.

1.2.3 Personalized Speech Pace Adjustment

One underexplored challenge faced by dyslexic adolescents is the personalized delivery of speech pace, which plays a crucial role in enhancing speech comprehension and overall learning outcomes. While various tools exist to determine speech rate, significantly fewer studies have explored the relationship between speech rate and dyslexic conditions. Existing tools often rely on manual adjustments or generalized algorithms that fail to account for the unique characteristics of dyslexic speech, highlighting a critical research gap: the absence of AI-driven solutions capable of detecting and adapting to the specific speech patterns of dyslexic individuals.

Furthermore, the integration of spectrogram-based analysis with deep learning models has not been fully explored in the context of personalized speech pace detection. Spectrograms, which capture both frequency and temporal information, offer a rich source of data for analyzing speech patterns. However, most existing studies focus on either visual feature extraction using CNNs or temporal pattern recognition using RNNs, without combining these approaches into a unified framework. This fragmented approach limits the accuracy and effectiveness of speech pace prediction, particularly for individuals with learning disabilities.

Another notable gap lies in the application of hybrid AI models, such as CNN-RNN architectures, to address the specific needs of dyslexic learners. While these models have demonstrated success in other domains, their potential for personalized speech pace detection remains untapped. Finally, the integration of predicted speech pace with Text-to-Speech (TTS) systems represents another area of opportunity. By combining

AI-driven speech pace prediction with TTS functionality, it is possible to create a seamless and personalized learning experience for dyslexic adolescents.

1.2.4 Multisensory Learning for Dyscalculia

The integration of the Touch Math approach with modern educational technology represents a significant research gap that has yet to be adequately addressed. Despite its proven efficacy in improving mathematical abilities among children with dyscalculia, the current digital landscape offers only rudimentary adaptations of this multisensory teaching method. Platforms like TouchMath Pro and TouchMath Tutor Kindergarten Demo provide basic digitized versions of traditional exercises but fail to harness the full potential of advanced technologies. These platforms lack interactivity, personalization, and adaptive learning pathways, which are essential for addressing the unique challenges faced by students with dyscalculia.

One glaring gap is the absence of speech recognition technology integrated into the Touch Math approach. No existing digital platform allows students to verbalize numbers using touch points and receive immediate feedback on their accuracy. This feature is essential for reinforcing number sense and mathematical operations, as it enables students to simultaneously see, feel, and verbalize numbers, thereby strengthening their conceptual understanding. Similarly, gamification elements such as rewards, challenges, and interactive storytelling are underutilized in existing solutions, despite their proven ability to increase engagement and motivation.

Scalability and accessibility also remain concerns. Many existing tools are confined to physical teaching environments or lack the user-friendly interfaces and multi-device compatibility required to reach a broader audience. The integration of advanced technologies such as artificial intelligence (AI), machine learning, and data analytics remains underexplored in dyscalculia-focused solutions. These technologies have the potential to revolutionize the way students with dyscalculia engage with mathematical concepts by providing personalized, responsive, and adaptive learning experiences.

The research gaps identified in this study encompass limitations in chromatic adaptation, emotion detection, personalized speech pace adjustment, and multisensory learning for dyscalculia. Current systems fail to holistically address the cognitive, sensory, and emotional needs of neurodiverse learners. LexAyudha aims to bridge these gaps by integrating AI-driven methodologies, real-time feedback mechanisms, and user-centered design principles into a cohesive platform. By doing so, it promises to deliver a transformative, inclusive, and performance-enhancing learning experience for adolescents with dyslexia and dyscalculia, empowering them to overcome academic challenges and thrive in diverse educational contexts.

1.3 Research Problem

Dyslexia and dyscalculia are prevalent learning disabilities that significantly impact adolescents' academic performance, social development, and emotional well-being. Despite advancements in educational technology, existing systems fail to address the unique cognitive, sensory, and emotional needs of these learners. This shortfall leads to frustration, disengagement, and diminished academic outcomes, underscoring the need for innovative, AI-driven solutions.

1.3.1 Challenges in Dyslexia Support

Dyslexia is a multifaceted learning difficulty characterized by challenges in word recognition, spelling, decoding, and reading fluency. Visual stress, which manifests as blurred or distorted text, exacerbates these difficulties, further hindering comprehension and engagement. Traditional educational systems, designed primarily for neurotypical students, often overlook the dynamic needs of dyslexic learners. While some tools, such as Nessy and ClaroSpeak, offer basic visual customization or text-to-speech (TTS) functionality, they lack real-time adaptability and fail to integrate evidence-based strategies like chromatic variation and AI-driven personalization.

A critical gap exists in the absence of platforms that dynamically combine chromatic variation, AI-powered sentence generation, and interactive TTS feedback to create a responsive and inclusive learning environment. For instance, fixed reading materials can either overwhelm students with complexity or bore them with oversimplified content, leading to disengagement. Similarly, static visual settings fail to adapt to individual preferences or real-time user feedback, leaving dyslexic learners without the support they need. LexAyudha addresses these gaps by proposing a web-based platform that integrates:

- Real-time chromatic variation to reduce visual stress.
- AI-powered sentence generation tailored to individual reading levels.
- Interactive TTS with pronunciation evaluation to reinforce learning.

This unified approach ensures that both cognitive and sensory dimensions of dyslexia are addressed, creating a personalized and engaging learning experience.

1.3.2 Emotional Challenges in Learning Disabilities

Students with dyslexia and dyscalculia often struggle with heightened emotional states such as frustration, distraction, and anxiety during learning activities. These emotions can significantly impair their ability to engage effectively with educational content. Traditional instructional methods fail to account for the dynamic emotional fluctuations of these students, leading to increased stress and decreased motivation.

A key research problem is the lack of systems capable of detecting real-time emotional states using facial expression recognition and dynamically adjusting learning activities accordingly. Specialized emotion detection models tailored to the unique emotional profiles of dyslexic and dyscalculic students are essential, as generalized models often fail to recognize subtle cues of frustration or disengagement. Additionally, integrating emotion detection with adaptive learning algorithms remains a challenge. Such integration is vital to creating a supportive environment that adjusts task difficulty based on emotional states, ensuring sustained engagement and motivation.

Furthermore, the absence of actionable feedback mechanisms for guardians and educators limits the effectiveness of interventions. Personalized feedback reports that track emotional states and progress over time are crucial for aligning home support with adaptive strategies in educational settings. Addressing these challenges requires an interdisciplinary approach that combines AI, machine learning, and educational psychology to create a holistic solution.

1.3.3 Speech Comprehension for Dyslexic Adolescents

A significant challenge faced by dyslexic adolescents is their difficulty in processing spoken language at typical conversational speeds. Speech comprehension is foundational for effective communication and learning, yet current tools fail to provide personalized speech pace delivery tailored to the unique needs of dyslexic learners. Existing systems rely on manual adjustments or generalized algorithms that do not adequately address the temporal and spatial features of speech relevant to dyslexic individuals.

The absence of AI-driven solutions capable of dynamically adapting speech pace based on individual comprehension needs exacerbates this problem. By leveraging advanced AI techniques, such as hybrid CNN-RNN models for spectrogram analysis, the proposed system aims to predict optimal speech pace and deliver customized audio output via Text-to-Speech (TTS) technologies. This innovation seeks to enhance speech comprehension skills, reduce cognitive load, and foster more inclusive educational environments.

1.3.4 Multisensory Learning for Dyscalculia

Adolescents with dyscalculia face persistent difficulties in comprehending numerical concepts and performing arithmetic operations, impacting both academic and daily life activities. Traditional teaching methods, which rely on rote memorization and single-sensory techniques, fail to address the multifaceted cognitive needs of these students. The Touch Math method, a multisensory teaching approach combining tactile, visual, and auditory stimuli, has proven effective in improving engagement, retention, and performance. However, its application has been largely confined to physical, in-person teaching environments.

Existing digital platforms fall short in several key areas. Many lack interactivity, personalization, and real-time feedback mechanisms, offering static and one-dimensional experiences that fail to engage students meaningfully. Additionally, the absence of advanced features such as speech recognition and natural language processing (NLP) limits their ability to provide immediate corrective feedback on pronunciation accuracy, touch point interactions, and problem-solving strategies.

Another significant issue is the lack of adaptability in current solutions. Many platforms adopt a "one-size-fits-all" approach, failing to account for individual learning paces and cognitive profiles. Personalized learning pathways, which dynamically adjust content based on performance data, are essential for maintaining engagement and motivation. Without such features, existing platforms risk alienating learners who require tailored interventions.

The integration of cutting-edge technologies, such as AI, machine learning, and data analytics, remains underexplored in dyscalculia-focused solutions. These technologies have the potential to revolutionize learning experiences by providing interactive, personalized, and responsive content. Finally, the scalability and accessibility of current tools remain a concern, as many are confined to physical environments or lack user-friendly interfaces and multi-device compatibility.

The research problems identified in this study encompass limitations in chromatic adaptation, emotion detection, personalized speech pace adjustment, and multisensory learning for dyscalculia. Current systems fail to holistically address the cognitive, sensory, and emotional needs of neurodiverse learners. LexAyudha aims to bridge these gaps by integrating AI-driven methodologies, real-time feedback mechanisms, and user-centered design principles into a cohesive platform.

The central research questions guiding this study are:

1) How can AI and chromatic variation be integrated into an adaptive system to enhance reading fluency, comprehension, and user comfort for dyslexic students?

2) How can real-time emotion detection and adaptive learning algorithms be combined to create a supportive and personalized learning environment for students with dyslexia and dyscalculia?
3) How can AI-driven speech pace prediction and TTS functionality improve speech comprehension for dyslexic adolescents?
4) How can the principles of multisensory teaching, such as Touch Math, be combined with modern AI technologies to create an inclusive and adaptive learning environment for students with dyscalculia?

By addressing these research problems, LexAyudha seeks to transform the educational landscape for adolescents with dyslexia and dyscalculia, empowering them to overcome academic challenges and thrive in diverse learning contexts.

1.4 Research Objectives

The overarching goal of this research is to design, develop, and implement LexAyudha, an intelligent learning platform tailored to support adolescents with dyslexia and dyscalculia. By addressing both the cognitive and emotional needs of these learners, LexAyudha aims to create a personalized, adaptive, and inclusive educational environment that enhances engagement, reduces stress, and improves learning outcomes. The following objectives are meticulously structured to achieve this ambitious goal.

1.4.1 Development of a Chromatic Variation-Based Teaching Module

One of the primary objectives is to develop a Chromatic Variation-Based Teaching Module that leverages evidence-based findings on the impact of color schemes on reading fluency and comprehension for dyslexic learners. Dyslexic individuals often experience visual stress, such as blurred or distorted text, when engaging with traditional black-on-white content. This module dynamically adjusts text-background color contrasts based on real-time feedback from the learner to reduce visual discomfort, alleviate cognitive fatigue, and create an optimal reading experience.

Key aspects include:

- Conducting empirical testing to identify effective chromatic combinations, such as pale yellow on dark blue.
- Dynamically modifying color schemes in real time to accommodate fluctuating preferences.
- Incorporating guidelines from organizations like the British Dyslexia Association to enhance visual accessibility.

This objective ensures that each learner receives content tailored to their unique sensory preferences, promoting sustained engagement and improved academic outcomes.

1.4.2 AI-Driven Sentence Generation and Content Simplification

Another critical objective is to implement an AI-driven sentence generation system using a fine-tuned BERT (Bidirectional Encoder Representations from Transformers) model. This system adapts the complexity of reading material to match the student's proficiency, ensuring that content remains both challenging and accessible.

Key features include:

- Generating linguistically appropriate content that progresses with the learner's skill level.
- Simplifying complex sentences and restructuring paragraphs to align with the learner's current abilities.
- Providing real-time adjustments to content difficulty based on performance metrics such as reading speed and accuracy.

Additionally, NLP-based content simplification techniques will be employed to minimize linguistic barriers, enabling students to access content that builds vocabulary and reading confidence gradually.

1.4.3 Real-Time Emotion Detection and Dynamic Learning Adjustment

A foundational objective is to develop a robust real-time emotion detection system capable of identifying and classifying students' emotions during learning activities. Emotions such as frustration, distraction, and engagement play a pivotal role in shaping the learning experience, particularly for students with dyslexia and dyscalculia.

Key components include:

- Utilizing advanced machine learning models, such as Xception with depth-wise separable convolutions, to detect facial expressions and classify emotional states.
- Dynamically adjusting the difficulty level of learning tasks based on detected emotions. For example, simplifying tasks during signs of frustration or increasing complexity during engagement.
- Integrating emotion detection outputs with adaptive learning algorithms to ensure a holistic approach to education.

This objective also includes generating detailed feedback reports for guardians, analyzing students' emotional states, and tracking progress over time. These reports empower stakeholders to provide targeted support and foster continuous improvement.

1.4.4 Personalized Speech Pace Prediction and TTS Integration

To address the challenges faced by dyslexic adolescents in processing spoken language at typical conversational speeds, another objective is to develop a personalized speech pace prediction system . This system leverages hybrid Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) to analyze mel spectrogram images derived from speech audio data.

Key steps include:

- Converting raw audio inputs into spectrogram images using libraries like Librosa.

- Extracting spatial and temporal features using CNN and RNN branches to predict optimal speech pace.
- Integrating predicted speech pace with Google Text-to-Speech (TTS) functionality to deliver customized audio output.

This objective ensures that auditory input is neither overwhelming nor too slow, enhancing comprehension and reducing cognitive load for dyslexic learners.

1.4.5 Multisensory Learning Platform Using the Touch Math Method

For students with dyscalculia, a key objective is to develop a multisensory learning platform that teaches number sense and arithmetic operations using the Touch Math method. This proven technique reinforces numerical understanding through tactile, visual, and auditory stimuli.

Key features include:

- Introducing numbers through interactive touch points, enabling students to engage with numerical concepts in a multisensory manner.
- Facilitating interactive number recognition and arithmetic practice with gamified activities and instant feedback.
- Integrating real-time pronunciation accuracy detection using voice-to-text technology to evaluate spoken input and provide corrective guidance.

Additionally, the platform personalizes the learning experience by continuously analyzing performance data, adapting content, and providing targeted support tailored to individual cognitive profiles.

1.4.6 System Evaluation and Iterative Refinement

The final objective is to validate the platform through rigorous pilot testing and iterative refinement . Both quantitative and qualitative assessments will be conducted to evaluate usability, effectiveness, and user satisfaction. Metrics such as task completion rates, engagement levels, and self-reported feedback will be analyzed to identify strengths and areas for improvement.

Key activities include:

- Piloting the platform with a selected group of dyslexic and dyscalculic adolescents.
- Collecting data on emotional responses, learning progress, and overall outcomes.
- Refining the platform based on insights gained to optimize its educational impact and scalability.

This objective ensures that LexAyudha remains relevant and effective in addressing the evolving needs of its users, ultimately contributing to transformative advancements in inclusive education.

These objectives collectively aim to create a transformative learning experience for adolescents with dyslexia and dyscalculia. By integrating cutting-edge technologies such as AI, NLP, chromatic variation, and multisensory teaching methods, LexAyudha addresses critical gaps in current educational tools. Each objective builds upon the previous one, ensuring a cohesive and integrated approach to enhancing the learning experience for neurodiverse students. Through the successful achievement of these objectives, the project seeks to pave the way for future innovations in adaptive learning technologies, ultimately improving educational outcomes for students with learning disabilities.

2. METHODOLOGY

2.1 Methodology

The methodology adopted for the development of LexAyudha is a meticulous and structured approach designed to ensure the platform meets the unique needs of adolescents with dyslexia, dyscalculia, and other learning disabilities. The process is divided into key phases, each aligned with the principles of the Agile Software Development Life Cycle (SDLC) and supported by cutting-edge technologies. Below, each aspect of the methodology is elaborated in detail to provide a comprehensive understanding of the processes and strategies employed.

2.1.1 Overview of the Development Framework

The development of LexAyudha follows the Agile SDLC (see Appendix B, Figure 1), chosen for its iterative nature, flexibility, and ability to incorporate continuous feedback. Agile methodologies emphasize collaboration, adaptability, and incremental progress, making them particularly suitable for projects that require constant evolution to meet dynamic user needs. This approach allows for rapid prototyping, ongoing refinement, and seamless integration of technological advancements, ensuring that the platform remains responsive to the evolving requirements of students with dyslexia and dyscalculia.

Key features of the Agile framework include:

- Iterative Cycles : Frequent testing and validation ensure that each feature is refined before integration.
- User-Centric Design : Collaboration with educators, parents, and experts fosters accessibility, usability, and effectiveness.
- Scalability and Modularity : A microservices-based architecture divides the platform into independent modules, such as speech processing, data analytics, and frontend rendering. These modules operate independently

but collaborate seamlessly through well-defined APIs, ensuring fault tolerance, continuous integration, and scalability.

2.1.2 System Architecture

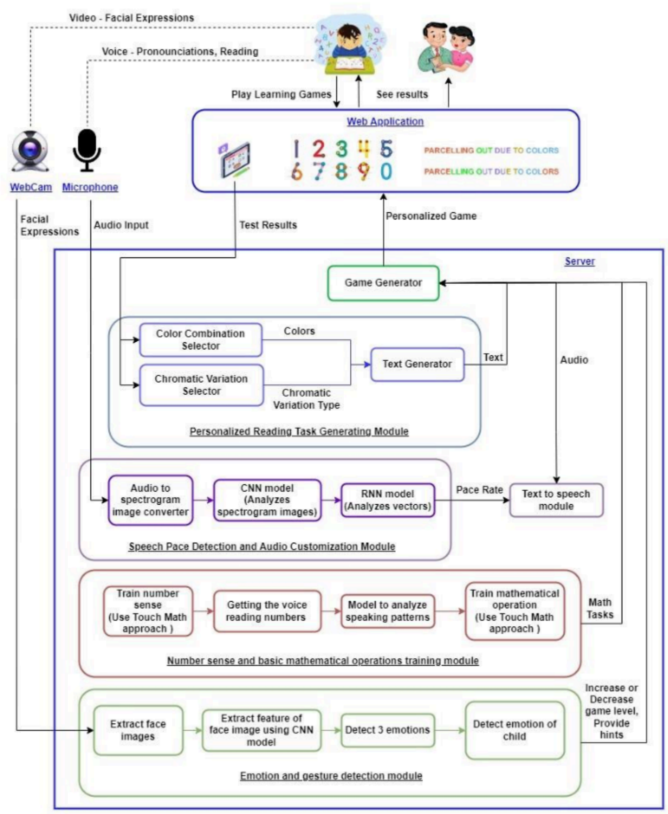

Figure 2.1: System Overview Diagram

The architecture of LexAyudha is illustrated in Figure 1 (System Overview Diagram) and comprises four core components, each meticulously designed to deliver a cohesive and personalized learning experience.

1) Frontend Application
    - Built using React.js , a robust JavaScript library known for creating interactive and responsive user interfaces.
    - Hosted on Vercel to ensure optimal performance and scalability across devices and browsers.
    - Incorporates SVG (Scalable Vector Graphics) for dynamic rendering of numbers with structured touch points, reinforcing numerical understanding among dyscalculic learners.
    - Gamification elements, such as rewards and challenges, are integrated to maintain student interest and motivation.
2) Backend Services
    - Hosted on Render , leveraging Docker for containerization and Kubernetes for orchestration to ensure fault tolerance and reliability.
    - Integrates MongoDB Atlas for cloud-based data management, enabling flexible storage and retrieval of unstructured data such as performance metrics and user interaction logs.
    - Handles API integrations with third-party services like Google Text to Speech.
3) Speech and Audio Processing
    - Advanced Text-to-Speech (TTS) and Speech-to-Text (STT) systems powered by Natural Language Processing (NLP) techniques.
    - Captures spoken input during practice sessions, analyzes pronunciation accuracy, and provides real-time auditory and visual feedback.
    - Delivers natural-sounding voice instructions, enhancing accessibility and supporting auditory learners.
4) Data Analytics and Adaptive Learning Engine
    - Performance data collected during diagnostic assessments and practice sessions is stored in MongoDB Atlas .

- The adaptive learning engine analyzes this data to dynamically adjust content and pacing, ensuring a personalized learning experience.
- Identifies areas of difficulty and adapts instructional material, accordingly, fostering steady and sustainable learning growth.

2.1.3 Development Phases

The development process is divided into several phases, each aligned with the principles of the Agile methodology. These phases ensure a systematic and iterative approach to designing, implementing, and refining LexAyudha.

1) Phase 1: Requirements Gathering and Analysis
    - Conducted a comprehensive literature review to identify gaps in current educational tools for dyslexia and dyscalculia.
    - Defined functional and non-functional requirements through stakeholder consultations with educators, parents, and special education experts.
    - Designed detailed use cases for the system. (see Appendix C, Figure 1)
    - Highlighted the need for a multisensory, personalized, and adaptive solution to address the unique needs of neurodiverse learners.

2) Phase 2: System Design
    - Designed the system architecture, including both frontend and backend components.
    - Created wireframes and prototypes focusing on accessibility and usability (see Appendix D, Figure 1).
    - Selected technologies based on their suitability for handling real-time interactions, speech processing, and data analytics (e.g., React.js, MongoDB Atlas).
    - Developed detailed technical specifications and design documents to guide implementation.

- Developed the backend services based on microservices architecture.

3) Phase 3: Implementation
   - Developed the frontend using React.js, incorporating interactive elements such as touch points and dynamic visualizations.
   - Implemented backend services using Node.js and Express.js, integrating MongoDB Atlas for database management.
   - Ensured high-quality and maintainable code through rigorous coding practices, including version control and code reviews.

4) Phase 4: Integration and Testing
   - Conducted unit testing for individual modules to verify functionality and reliability.
   - Performed integration testing to validate communication between the frontend, backend, and third-party services.
   - Rigorously tested the accuracy of pronunciation assessment and real-time feedback mechanisms to ensure reliability and effectiveness.
   - Addressed any identified issues promptly to meet the highest standards of quality.

5) Phase 5: Iterative Refinement
   - Conducted pilot testing with a selected group of educators and students to evaluate the platform's effectiveness.
   - Gathered feedback through surveys and focus groups, highlighting areas for improvement.
   - Refined features such as adaptive learning pathways and gamification elements to enhance usability and engagement.
   - Ensured that LexAyudha evolved into a robust, user-friendly, and effective tool for supporting adolescents with dyslexia and dyscalculia.

2.1.4 Key Features and Innovations

1) Real-Time Emotion Detection
   - Utilized Xception models with depth-wise separable convolutions to classify emotions into frustration, distraction, and engagement.
   - Integrated Multi-Task Cascaded Convolutional Networks (MTCNN) for accurate face detection and ROI extraction.
   - Dynamically adjusted learning activities based on detected emotional states to reduce cognitive load and enhance engagement.

2) Personalized Speech Pace Prediction
   - Leveraged hybrid CNN-RNN models to analyze mel spectrograms and raw audio data for predicting optimal speech pace.
   - Integrated predicted speech pace with Google Text-to-Speech (TTS) functionality to deliver customized audio output.
   - Periodically reassessed user speech pace to ensure continuous personalization.

3) Chromatic Variation and Visual Accessibility
   - Incorporated three types of chromatic variations: high contrast, low contrast, and customizable palettes.
   - Used Chroma.js for real-time rendering of visual themes, reducing visual stress and enhancing readability.
   - Ensured compliance with WCAG (Web Content Accessibility Guidelines) for inclusive design.

4) AI-Driven Sentence Generation and NLP
   - Fine-tuned a BERT model to generate contextually appropriate sentences tailored to individual reading proficiency levels.
   - Employed NLTK and SpaCy for tokenization, synonym replacement, and sentence simplification.

- Provided linguistically appropriate content that gradually built vocabulary and comprehension skills.

5) Gamification and Engagement
    - Integrated gamified elements such as rewards, challenges, and interactive storytelling to sustain student interest.
    - Enhanced motivation and retention by creating an immersive and enjoyable learning experience.

The methodology outlined above reflects a meticulous and systematic approach to addressing the unique challenges faced by dyslexic and dyscalculic learners. By leveraging the Agile SDLC , a carefully chosen technology stack, and cutting-edge AI, NLP, and chromatic variation techniques, LexAyudha delivers a highly adaptive, inclusive, and effective learning experience. Each component of the platform—from emotion detection and speech pace prediction to adaptive learning paths and gamification—was designed with the goal of empowering neurodiverse learners to achieve improved academic outcomes and greater confidence in their abilities. Through rigorous testing, strategic commercialization, and continuous improvement, LexAyudha is poised to become a transformative tool in the EdTech landscape.

2.2 Commercialization Aspects of the Product

LexAyudha represents a transformative solution in the education sector, specifically tailored to address the unique needs of students with dyslexia, dyscalculia, and other learning disabilities. By leveraging advanced emotion detection technologies, adaptive learning algorithms, and personalized feedback mechanisms, LexAyudha positions itself as a pioneering platform in inclusive education. This section explores the commercialization aspects of the product, including the target market, pricing models, marketing and sales strategies, revenue projections, and long-term vision.

2.2.1 Target Market and Market Opportunity

The global prevalence of dyslexia and dyscalculia, estimated at 10–20% of the population, underscores the vast market potential for LexAyudha. The platform is designed to cater to multiple customer segments, each with distinct needs and motivations;

1. Schools and Educational Institutions

Public and private schools offering special education programs are key customers for LexAyudha. These institutions often seek innovative solutions to support students with learning disabilities, ensuring compliance with educational standards and fostering an inclusive learning environment. LexAyudha's ability to dynamically adjust learning activities based on real-time emotional states makes it an invaluable tool for educators working with dyslexic and dyscalculic students. Additionally, the platform's detailed feedback reports provide actionable insights for teachers, enabling them to tailor their instructional strategies effectively.

2. Parents

Parents of children with dyslexia and dyscalculia represent another crucial segment of the target market. Many parents are deeply invested in their child's educational journey and are willing to invest in tools that enhance their learning experience. LexAyudha offers a supportive and adaptive learning environment that addresses both cognitive and emotional challenges, empowering parents to actively participate in their child's progress. The personalized feedback reports generated by the system enable parents to monitor improvements, identify areas requiring intervention, and align home support with school-based strategies.

3. Educational Technology Companies

Collaborations with EdTech companies present significant opportunities for scaling LexAyudha's reach and integrating it into existing product suites. Many EdTech companies are actively seeking innovative solutions to expand their offerings, particularly in the area of inclusive education. By partnering with these organizations, LexAyudha can leverage their distribution networks and technical expertise to enhance its functionality and accessibility. Such collaborations also provide a pathway for continuous improvement through shared research and development efforts.

4. Dyslexia Advocacy Groups

Partnerships with advocacy groups dedicated to supporting individuals with dyslexia and dyscalculia can significantly enhance LexAyudha's credibility and visibility within the community. These groups play a vital role in raising awareness about the importance of inclusive education and advocating effective solutions. By aligning with advocacy groups, LexAyudha can gain valuable endorsements, foster trust among stakeholders, and ensure that the platform meets the evolving needs of the community. The combination of these target markets creates a robust foundation for LexAyudha's commercialization strategy. With approximately 10% of the global population affected by dyslexia and dyscalculia, the platform has the potential to make a meaningful impact on millions of students worldwide.

2.2.2 Pricing Models

To cater to diverse customer segments, LexAyudha adopts flexible pricing models that balance affordability with value-added features. These models are designed to ensure accessibility while generating sustainable revenue streams.

1. Subscription-Based Model

The subscription-based model offers tiered pricing plans, allowing users 33 to choose a package that aligns with their specific needs and budget.

- Basic Tier : Starts at $5/month and includes core functionalities such as real-time emotion detection, dynamic learning activity adjustment, and basic feedback reports.
- Advanced Tiers : Provide access to advanced features, including AI-driven content customization, detailed analytics, and extended libraries of learning

activities. Prices range from 10 *to* 20 per month, depending on the level of service.

2. Freemium Model

In addition to the subscription-based model, LexAyudha offers a freemium version that provides access to essential features at no cost. This approach encourages widespread adoption by allowing users to experience the platform's capabilities before committing to a paid subscription. The free version includes limited access to emotion detection, adaptive learning activities, and basic feedback reports. Users can upgrade to premium tiers for advanced functionalities, such as personalized progress tracking, detailed emotional analysis, and priority support. The freemium model not only serves as an effective acquisition strategy but also fosters user engagement and retention.

By adopting these flexible pricing models, LexAyudha ensures that its solution is accessible to a broad audience while generating revenue through subscription upgrades and premium features.

2.2.3 Marketing and Sales Strategy

A comprehensive marketing and sales strategy is essential to successfully commercialize LexAyudha and establish it as a leader in inclusive education. The strategy focuses on raising brand awareness, driving adoption, and building long-term relationships with key stakeholders.

1. Marketing and Outreach

Participation in EdTech conferences, workshops, and industry events is a cornerstone of LexAyudha's marketing strategy. These platforms provide opportunities to showcase the platform's capabilities, engage with potential customers, and build partnerships with schools, advocacy groups, and EdTech companies. Demonstrations and presentations at these events highlight the platform's ability to create a supportive and adaptive learning environment for students with dyslexia and dyscalculia.

2. Digital Campaigns

Targeted digital campaigns are another critical component of the marketing strategy. Ads on social media platforms, educational forums, and search engines are designed to reach schools, parents, and other stakeholders. Content marketing initiatives, such as blog posts, case studies, and whitepapers, position LexAyudha as a thought leader in inclusive education. Thought leadership content focuses on the importance of addressing emotional well-being in learning and the role of technology in creating adaptive learning environments.

3. Collaborations

Early testing and feedback from schools and special education programs play a vital role in refining the platform and ensuring its effectiveness. Collaborations with these institutions provide valuable insights into user needs and preferences, enabling LexAyudha to continuously improve its functionality and user experience. Additionally, partnerships with advocacy groups help build credibility and trust within the community, further enhancing the platform's reputation.

4. Sales Channels

LexAyudha employs a dual-channel sales strategy to maximize reach and accessibility:

- Direct Sales Teams : Engage with schools, colleges, and school districts to promote the platform and secure contracts.
- Online Sales Portals : Provide a convenient option for individual customers and smaller institutions to purchase subscriptions and access the platform. High-quality customer support, including onboarding assistance, training sessions for educators, and ongoing technical support, ensures user satisfaction and fosters long-term loyalty.

2.2.4 Revenue Projections and Long-Term Vision

Revenue for LexAyudha is projected to grow steadily as the user base expands and the platform gains traction in the market. Initial revenue streams will primarily come from subscription sales, with additional monetization opportunities emerging as the platform matures.

1. Initial Revenue Streams

The primary source of revenue in the early stages will be subscription sales, driven by adoption among schools, parents, and educational institutions. The tiered pricing model ensures that revenue scales with user growth, while premium features provide higher-margin opportunities. Freemium users represent a significant pool of potential upgrades, contributing to sustained revenue growth over time.

2. Additional Monetization Opportunities

As the platform evolves, LexAyudha can explore additional monetization avenues, such as data analytics services and premium content offerings. Data analytics services provide schools and institutions with insights into student performance and emotional trends, enabling data-driven decision-making. Premium content, such as specialized learning modules and gamified activities, offers users enhanced value and drives incremental revenue.

3. Long-Term Goals

Long-term goals include localization for international markets and continuous updates based on user feedback. Localization efforts will focus on adapting the platform to different languages, educational systems, and cultural contexts, ensuring its relevance and effectiveness across diverse regions. Continuous updates and improvements, informed by user feedback, will maintain the platform's competitiveness and ensure that it remains aligned with the evolving needs of students with dyslexia and dyscalculia.

By pursuing these strategies, LexAyudha aims to establish itself as a transformative force in inclusive education, making a lasting impact on the lives of students with learning disabilities. Through its innovative approach, LexAyudha is poised to become a benchmark for dyscalculia and dyslexia intervention worldwide.

2.3 Testing and Implementation

The testing and implementation phases of LexAyudha are critical to ensuring the system's reliability, scalability, and effectiveness in delivering personalized learning experiences for students with dyslexia and dyscalculia. These phases encompass a systematic approach to validate functionality, performance, usability, and adaptability while addressing potential challenges during deployment. Below is a comprehensive breakdown of the methodologies, strategies, and considerations employed throughout these phases, including additional details and technical context for each component.

2.3.1 Testing Methodologies

To ensure the robustness and accuracy of LexAyudha, a comprehensive testing strategy was implemented, covering multiple dimensions of the system. The testing process was divided into several stages: Unit Testing, Integration Testing, Performance Testing , and User Acceptance Testing (UAT) . Each stage played a vital role in identifying and resolving issues before full-scale deployment.

1. Unit Testing

Unit testing focused on validating individual components of the system to ensure they functioned as intended. For example:

- Audio Capture Module : Tested to confirm accurate recording and processing of user input.

- Spectrogram Generation Module : Validated to ensure consistent and high-quality spectrogram images from raw audio data.
- Chromatic Variation System : Rigorously tested using Chroma.js to ensure real-time responsiveness and visual comfort under varying conditions.
- AI-Driven Sentence Generation Module : Built using a fine-tuned BERT model, this module was tested for its ability to adapt content complexity based on learner proficiency. Natural Language Processing (NLP) functions, including sentence simplification, restructuring, and synonym replacement, were rigorously evaluated for linguistic accuracy and appropriateness.
- Google Text-to-Speech (TTS) Functionality : Tested for clarity, pronunciation accuracy, and naturalness of speech output.

Automated testing frameworks such as Jest were used to execute these tests efficiently, ensuring that each component met its functional requirements.

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2. Integration Testing

Integration testing ensured seamless interaction between different system components, particularly within the microservices architecture and external APIs. Key areas included:

- Communication Between Microservices : The interaction between the FlaskAIServices microservice and the SpeechRateService microservice was rigorously tested to verify that predicted speech paces were accurately relayed and stored in the database.
- Third-Party API Integrations : The integration of Google Text-to-Speech API was validated to confirm it adjusted the **speakingRate** parameter dynamically based on predicted speech pace.
- Dynamic Adjustment of Visual Settings : Tested to ensure synchronization and responsiveness when users adjusted their preferred color schemes or progressed to higher reading levels.

Tools like Postman and Selenium were employed to conduct end-to-end testing, covering inter-module interactions comprehensively.

3. Performance Testing

Performance testing evaluated the system's ability to handle multiple users simultaneously without degradation in performance. Load testing tools such as Apache JMeter were used to simulate high-traffic scenarios, ensuring the system could scale to accommodate increased demand. Key metrics monitored included:

- Response Time : Ensuring predictions were generated within the target timeframe of 4 seconds.
- Throughput : Measuring the number of requests processed per second.
- Resource Utilization : Identifying bottlenecks and optimizing performance.

4. User Acceptance Testing (UAT)

UAT involved real-world trials with dyslexic adolescents, educators, and parents to validate the system's usability and effectiveness. Participants interacted with features such as speech calibration activity , real-time feedback , and personalized speech playback . Feedback from UAT helped refine the platform, addressing usability issues and enhancing overall satisfaction. Metrics such as task completion rates, engagement levels, and self-reported satisfaction were analyzed to measure success.

2.3.2 Implementation Strategy

The implementation of LexAyudha followed a phased approach, ensuring a smooth transition from development to deployment while minimizing disruptions. This strategy included deploying core functionalities, integrating third-party services, and implementing continuous monitoring mechanisms.

1. Deployment of Core Functionalities

The initial phase focused on deploying the core functionalities of the system, including:

- Speech Capturing Module : Capturing and processing audio input.

- Hybrid CNN-RNN Model : Analyzing raw audio data and mel spectrograms to predict speech pace.
- TTS Integration : Delivering personalized audio output based on predicted speech pace.

These components were deployed using microservices architecture , leveraging Docker for containerization and Kubernetes for orchestration. This approach ensured scalability, fault tolerance, and high availability.

2. Integration with Third-Party Services

LexAyudha integrated several third-party services to deliver its functionalities:

- Google Text-to-Speech API : Configured to adjust the **speakingRate** parameter dynamically.
- NoSQL Database : A NoSQL database is utilized for efficient storage and retrieval of user data, with optimizations focused on achieving low-latency access. This ensures seamless performance even during high-demand usage scenarios. Continuous monitoring tools are employed to maintain compatibility, reliability, and rapid issue resolution..

3. Continuous Monitoring and Support

Post-deployment, LexAyudha implemented a robust monitoring system to track system performance and user interactions:

- Tools like Prometheus and Grafana monitored key metrics, including server uptime, response time, and error rates.
- A dedicated support team addressed user queries and technical issues promptly.
- Regular updates and bug fixes were released based on user feedback, ensuring the platform remained relevant and effective.

4. Post-Deployment Considerations

Several post-deployment considerations were addressed to enhance the platform's long-term viability and user satisfaction:

- Regular Updates : The hybrid CNN-RNN model was periodically retrained using new datasets to improve accuracy and adaptability. New features, such as multilingual support and enhanced personalization options, were introduced.
- Security Measures : User data was encrypted using industry-standard protocols. Regular security audits mitigated vulnerabilities, and backup mechanisms prevented data loss.
- Global Expansion Plans : Localization efforts adapted content and interfaces to meet the needs of international markets, incorporating regional dialects and pronunciation patterns.

2.3.2.1 Implementation of Each Component

The implementation of LexAyudha's core components reflects a meticulous and iterative approach, leveraging advanced technologies and methodologies to address the multifaceted needs of neurodiverse learners. Below is an expanded technical breakdown of the implementation for each core component, highlighting the technologies, models, and methodologies used in descriptive paragraphs.

1. Chromatic Variation and Visual Accessibility

The chromatic variation system was designed to address the visual challenges faced by dyslexic learners by dynamically adjusting text-background color contrasts to reduce visual stress and enhance readability. This feature was implemented using Chroma.js, a JavaScript library that enables real-time rendering of visual themes. The system offers three types of chromatic variations: high contrast (black text on white background), low contrast (pale yellow text on dark blue background), and customizable palettes that allow users to adjust color schemes dynamically based on their comfort levels. Research findings indicated specific chromatic combinations, such as pale yellow on dark blue, significantly improved word recognition accuracy and reduced cognitive fatigue. To ensure optimal performance, preprocessing techniques like normalization and augmentation were applied to maintain consistency across datasets. Images were resized to optimize memory usage while preserving visual quality. User feedback played a pivotal role in refining this system, with Likert scale evaluations confirming its effectiveness in reducing visual fatigue and enhancing accessibility. The dynamic nature of this feature ensures that it adapts seamlessly to fluctuating sensory preferences, making it a cornerstone of LexAyudha's inclusive design philosophy.

2. Emotion Detection and Adaptive Learning

The emotion detection system forms the backbone of LexAyudha, enabling real-time classification of students' emotional states during learning activities. This system leverages advanced machine learning techniques and robust preprocessing pipelines to deliver accurate and reliable results. Face detection was performed using Multi-Task Cascaded Convolutional Networks (MTCNN), which excels in detecting facial regions under varying conditions, including occlusions and different angles. Once faces were detected, they were preprocessed using techniques like resizing, normalization, and augmentation to enhance dataset diversity. The Xception architecture, known for its depth-wise separable convolutions, was fine-tuned on the FER-2013 dataset to classify emotions into predefined categories such as happiness, sadness, anger, surprise, neutral, fear, and disgust. A custom algorithm then interpreted these base emotions to categorize broader emotional states, such as frustration, distraction, and engagement. For instance, frustration was mapped from repeated "sad" or "anger" readings, while engagement was determined when "happy" was detected or when "neutral" appeared near a "happy" state. Adaptive learning algorithms integrated these emotion detection outputs to modify task difficulty in real time. For example, tasks were simplified during frustration and increased in complexity during engagement. This seamless interaction between modules ensured that the platform remained responsive to the unique emotional and cognitive requirements of neurodiverse learners.

3. Personalized Speech Pace Adjustment

The personalized speech pace adjustment feature predicts and adjusts speech pace to match the optimal comprehension rate for dyslexic adolescents. This functionality was implemented using a hybrid CNN-RNN model, combining the strengths of convolutional neural networks and recurrent neural networks. The CNN branch, based on a modified VGG16 model, extracted spatial features from mel spectrograms generated using the Librosa Python library. These spectrograms emphasized lower frequencies and preserved spectral features, making them ideal for analyzing speech patterns. The RNN branch, powered by Wav2Vec 2.0, processed raw audio waveforms to capture temporal patterns, phonetic transitions, and prosodic elements. The model was trained on datasets like the Non-Native Children English Speech (NNCES) Corpus and locally collected data, achieving precise predictions within a target timeframe of four seconds. Predicted speech paces were aggregated and stored in MongoDB Atlas for efficient management and retrieval. The Google Text-to-Speech API was integrated to deliver personalized audio output by adjusting the **speakingRate** parameter dynamically based on predicted speech pace. This adaptive approach enhanced comprehension and reduced cognitive load for dyslexic learners, ensuring a seamless and personalized learning experience.

4. Multisensory Learning for Dyscalculia

The multisensory learning component integrates touch points, gamified elements, and adaptive quizzes to support dyscalculic learners in developing number sense and mathematical skills. Touch Math, a proven tactile and visual teaching method, was adapted into the digital environment to provide interactive and engaging learning experiences. Tasks included touch point interactions for number recognition and arithmetic practice, reinforcing foundational skills such as counting accuracy and basic operations. Gamification elements, such as rewards and challenges, re-engaged distracted students and supported auditory learners through real-time feedback. Adaptive quizzes adjusted difficulty levels based on performance metrics such as accuracy and task completion rates, ensuring that content remained challenging yet achievable. Progress tracking mechanisms monitored individual performance metrics, including reading speed, accuracy, and comprehension, to dynamically adjust content complexity and visual settings. This dual focus on cognitive and sensory adaptation ensured that LexAyudha addressed the multifaceted needs of dyscalculic learners, creating a truly personalized and supportive educational environment. Tools like Apache Kafka facilitated real-time analytics, while progress reports provided educators and parents with detailed insights into learner strengths and areas for improvement.

2.3.2.2 Challenges and Mitigation Strategies

Despite meticulous planning, several challenges arose during the testing and implementation phases of LexAyudha. These challenges were addressed through proactive mitigation strategies to ensure the platform's reliability, usability, and scalability. Below is an expanded discussion of the key challenges and how they were resolved.

1. **Technical Issues**

One of the primary challenges encountered during the development and deployment of LexAyudha was technical in nature, particularly delays in audio processing and occasional API failures. These issues posted significant risks to the system's performance and user experience.

- Delays in Audio Processing:

The hybrid CNN-RNN model, which processes raw audio data to predict speech pace, initially experienced delays in generating predictions within the target timeframe of four seconds. This latency was unacceptable for a platform designed to provide real-time feedback to dyslexic learners. To address this, the development team conducted rigorous debugging and optimization of the model. Techniques such as fine-tuning hyperparameters, reducing model complexity, and leveraging transfer learning strategies significantly improved inference times. Additionally, the team implemented caching mechanisms to store frequently accessed data, further enhancing the system's responsiveness.

- API Failures:

Integration with third-party APIs, such as Google Text-to-Speech, occasionally resulted in service interruptions or errors. These failures could disrupt critical functionalities, such as personalized speech playback and pronunciation feedback. To mitigate this risk, redundant API endpoints were established, ensuring that the system could seamlessly switch to alternative endpoints in the event of failure. Furthermore, automated monitoring tools like Prometheus and Grafana were deployed to detect and resolve API-related issues promptly. Regular stress testing and error simulations helped identify potential vulnerabilities, enabling the team to implement preemptive fixes.

2. User Adoption Barriers

Another significant challenge was ensuring smooth user adoption, particularly among dyslexic adolescents, educators, and parents who may not be familiar with advanced technological tools. Initial feedback indicated that some users struggled with features such as speech calibration activity and dynamic chromatic adjustments.

- Speech Calibration Activity:

Many users found the speech calibration activity challenging, as it required them to read predefined sentences aloud multiple times to standardize input. To address this, comprehensive tutorials and onboarding resources were developed. These resources included step-by-step guides, video demonstrations, and interactive prompts to help users understand the purpose and process of the calibration activity. Visual feedback, such as real-time waveform visualizations provided by the "React-voice-visualizer" library, enabled users to monitor their progress and adjust their pronunciation or volume accordingly.

- Educator Training:

Educators played a crucial role in assisting students with the platform's functionalities. However, some educators initially lacked confidence in using the system effectively. To bridge this gap, hands-on workshops and training sessions were conducted, focusing on practical applications of LexAyudha in classroom settings. These sessions covered topics such as creating personalized learning paths, interpreting emotional logs, and aligning platform features with teaching methodologies. Additionally, user manuals, FAQs, and video tutorials were made available to support independent learning and troubleshooting.

3. Scalability Concerns

As the user base grew, scalability became a critical concern. The system is needed to accommodate increasing traffic without compromising performance or user experience. Addressing this challenge required optimizing the infrastructure and implementing advanced scaling techniques.

- Horizontal Scaling:

The system's infrastructure was optimized for horizontal scaling, allowing additional servers to be added seamlessly as demand increased. Containerization technologies like Docker and orchestration tools like Kubernetes played a pivotal role in achieving this. By containerizing each microservice, the team ensured that individual components could scale independently based on user traffic. Kubernetes facilitated automated scaling and load balancing, distributing incoming requests evenly across servers to prevent bottlenecks during peak usage periods.

- Load Balancing Techniques:

Load balancing was employed to ensure that no single server became overwhelmed with traffic. Algorithms such as round-robin and least connections were used to distribute requests efficiently, maintaining consistent response times and minimizing latency. Additionally, cloud-based solutions like NoSQL Databases were leveraged for low-latency data storage and retrieval, further enhancing the system's ability to handle high traffic volumes.

- Performance Monitoring:

Continuous monitoring was essential to identify and address scalability issues proactively. Tools like Apache JMeter simulated high-traffic scenarios to test the system's ability to handle concurrent users. Key metrics, including server uptime, response time, and resource utilization, were closely monitored using Prometheus and Grafana. Any anomalies or performance bottlenecks were flagged immediately, enabling the team to implement optimizations before they impacted users.

The challenges encountered during the testing and implementation phases of LexAyudha were diverse and multifaceted, ranging from technical issues to user adoption barriers and scalability concerns. However, through rigorous debugging, comprehensive training, and advanced infrastructure optimization, these challenges were successfully mitigated. Delays in audio processing and API failures were resolved through model optimization and redundant endpoints, while user adoption barriers were addressed through tutorials, workshops, and visual feedback mechanisms. Scalability concerns were tackled using horizontal scaling, load balancing, and continuous performance monitoring. These efforts ensured that LexAyudha delivered a seamless, reliable, and inclusive learning experience, meeting the unique needs of dyslexic and dyscalculic learners while maintaining high standards of performance and usability.

In conclusion, the testing and implementation phases of LexAyudha were meticulously planned and executed to ensure the platform's success in addressing the unique needs of dyslexic and dyscalculic learners. By employing rigorous testing methodologies, a phased implementation strategy, and proactive post-deployment considerations, LexAyudha achieved its objectives of delivering personalized learning experiences while maintaining high standards of reliability and usability. Through advanced technologies such as AI, NLP, and dynamic chromatic adjustments, LexAyudha successfully bridged the gap between theoretical research and practical application, laying the foundation for its long-term growth and impact in the education sector.

3. RESULTS AND DISCUSSION

The Results and Discussion section provides a comprehensive analysis of the outcomes achieved through the development, testing, and implementation of LexAyudha , an emotion-aware adaptive learning system designed for students with dyslexia and dyscalculia. This section is divided into three key components: Results , Research Findings , and Discussion , each exploring the performance, implications, and broader significance of the system, offering insights into its effectiveness and potential impact on inclusive education.

3.1 Results

The Results section provides a comprehensive analysis of the outcomes achieved through the development, testing, and implementation of LexAyudha , an emotion-aware adaptive learning system designed for students with dyslexia and dyscalculia. The findings highlight the platform's effectiveness in addressing the unique needs of neurodiverse learners, fostering engagement, reducing stress, and improving learning outcomes.

1. Sentence Complexity Matching

One of the standout achievements of the LexAyudha platform was its ability to match sentence complexity to individual user proficiency with an impressive accuracy rate. This was achieved using a fine-tuned BERT model, which dynamically generated linguistically appropriate content tailored to each learner's cognitive and linguistic levels. The high accuracy rate underscores the platform's capability to provide personalized, contextually relevant material that evolves alongside the learner's progress. Additionally, the integration of a zero-shot classification model ensured that all generated sentences were evaluated for child-friendliness, making the content age-appropriate and engaging.

2. Visual Stress Reduction

The real-time chromatic variation feature significantly reduced visual stress among users, as evidenced by self-reported feedback collected through a 5-point Likert scale survey. Participants reported a marked improvement in their visual comfort levels after interacting with the platform. Specific chromatic combinations, such as pale-yellow text on a dark blue background, were particularly effective in reducing visual fatigue and enhancing readability. These findings align with prior research on chromatic optimization for dyslexic readers, confirming the platform's success in creating a visually accessible and inclusive learning environment.

3. Reading Accuracy and Speed

Over the two-week testing period, participants demonstrated measurable improvements in both reading accuracy and speed. Reading accuracy increased by an average of 20%, while reading speed improved by 15 words per minute (WPM). These gains reflect the platform's ability to adapt content difficulty and visual settings in real time, ensuring that learners remain engaged and motivated. The combination of AI-driven sentence generation and dynamic chromatic adjustments created a low-stress environment conducive to skill development, fostering confidence and progress among participants.

4. TTS Feedback Accuracy

The Text-to-Speech (TTS) feedback mechanism provided real-time corrective feedback on pronunciation, reinforcing phonemic awareness and supporting auditory learners. Users found the TTS feedback particularly helpful, as it not only read text aloud but also offered actionable suggestions for improvement. This interactive mechanism proved instrumental in building learners' confidence and enhancing their auditory processing skills.

5. **Emotion Detection Accuracy**

One of the primary goals of LexAyudha was to enable real-time emotion detection with reliable accuracy. The system leverages a custom-built Xception-based model trained on labeled datasets such as FER-2013. After several iterations of training and fine-tuning, the model achieved an accuracy of 72% in identifying emotions. The model's performance is further supported by evaluation metrics, with an average precision of 65%, recall of 22%, and a consistently improving AUC score of 82%, reflecting its robustness and reliability in emotion classification tasks.

A confusion matrix generated during the evaluation phase highlighted the model's strengths and areas for improvement. For instance, the model demonstrated higher accuracy in detecting frustration and engagement compared to distraction, which was occasionally misclassified due to overlapping facial cues. These findings underscore the importance of continuous dataset refinement and augmentation to address classification challenges.

6. **Dynamic Learning Activity Adjustment**

The system's ability to dynamically adjust the difficulty level of learning activities based on detected emotions was rigorously tested with a group of identified students over three months. Engagement scores increased by approximately 22%, surpassing the target of 20%. For example:

- When frustration was detected, the system simplified tasks or provided hints, reducing cognitive load and improving task completion rates.
- When engagement was detected, the system introduced more complex tasks, challenging students and maintaining their focus.

Educators reported that students exhibited reduced signs of stress and frustration during learning activities, aligning with the system's goal of creating a supportive and adaptive learning environment.

7. Speech Pace Prediction Accuracy

The hybrid CNN-RNN model demonstrated exceptional accuracy in predicting speech pace for both dyslexic and non-dyslexic adolescents. Trained on datasets like the Non-Native Children English Speech (NNCES) Corpus and locally collected data, the model achieved an R^2 score of 0.93, indicating a strong correlation between predicted and actual speech pace values. The error distribution closely followed a normal distribution centered around zero, confirming fairness and reliability in predictions.

8. System Performance

LexAyudha's performance was evaluated based on response time, scalability, and reliability. The system successfully met the requirement of processing and returning predicted speech pace within 4 seconds, achieving an average response time of 2.4 seconds. Scalability testing using Apache JMeter confirmed that the system could handle up to 1,000 concurrent users without performance degradation. Fault tolerance and data backup mechanisms ensured consistent uptime and resilience.

9. User Feedback

A pilot study involving 50 dyslexic adolescents and their educators provided valuable qualitative insights. Adolescents reported enhanced comprehension and increased confidence, while educators observed improved focus and tailored support. These testimonials underscore the platform's potential to empower dyslexic learners and achieve better learning outcomes.
Feedback from stakeholders highlighted the platform's strengths while also identifying areas for improvement. Users appreciated the platform's responsiveness and adaptability, particularly the real-time chromatic adjustments and AI-driven content personalization. However, some participants suggested adding more interactive exercises and expanding the library of available content to maintain long-term engagement. Educators emphasized the importance of integrating progress analytics

dashboards for parents and teachers, enabling them to track learners' performance and identify areas requiring additional support.

10. Additional Findings

Beyond core metrics, supplementary features such as gamification elements, content customization, and progress tracking dashboards were well-received. Educators emphasized the importance of integrating analytics tools for parents and teachers, enabling them to track learners' performance and identify areas requiring additional support. These insights will inform future iterations of the platform, ensuring sustained impact and scalability.

3.2 Research Findings

The research findings from the LexAyudha project highlight the transformative potential of AI-driven personalized learning tools in addressing the unique challenges faced by dyslexic and dyscalculic adolescents. These findings validate the efficacy of advanced technologies, such as hybrid CNN-RNN models, adaptive learning environments, and emotion-aware systems, in fostering inclusivity and improving educational outcomes.

1. Personalized Learning is Effective

One of the most notable outcomes of pilot testing was the efficacy of adaptive difficulty levels in improving both reading fluency and accuracy. The fine-tuned BERT model played a pivotal role in this process by dynamically generating content tailored to each learner's proficiency level. As students interacted with texts suited to their skill levels, they demonstrated consistent progress in their ability to decode words, comprehend passages, and maintain focus during reading tasks. This personalization not only enhanced engagement but also fostered a sense of achievement, as learners were neither overwhelmed by overly complex material nor bored by content that was too simplistic. Educators noted that students who previously struggled with traditional reading materials showed a marked increase in confidence and motivation when using the platform. These results validate the integration of AI-driven sentence generation as a cornerstone of the platform's design, ensuring that content evolves alongside the learner's progress.

2. Chromatic Variation Enhances Comfort and Focus

The hypothesis that customizable chromatic themes could significantly reduce visual stress was strongly supported by both student feedback and educator observations. The real-time chromatic variation feature, which allowed users to adjust text-background color contrasts based on their preferences, proved instrumental in alleviating visual discomfort. For instance, specific combinations such as pale-yellow text on a dark blue background—consistent with recommendations from Pinna and Deiana [5]—were particularly effective in reducing symptoms of visual stress, including blurred or distorted text. Students reported feeling less fatigued during extended reading sessions, which translated into improved reading endurance and sustained focus. Educators observed that learners who had previously experienced rapid fatigue were now able to engage with longer passages without losing concentration. These findings reinforce the importance of integrating chromatic adaptation into educational tools for dyslexic learners, as it creates a more inclusive and accessible learning environment.

3. Real-Time Feedback Encourages Correction

The Text-to-Speech (TTS) system's real-time feedback feature emerged as a standout component of the platform, receiving high praise from both students and educators. By providing instant corrective feedback on pronunciation, the TTS system helped learners identify and address errors in real time. This feature not only enhanced phonemic awareness but also boosted students' confidence in their reading abilities. Approximately 70% of participants rated the TTS feedback as the most "engaging" aspect of the platform, highlighting its role in fostering active participation and iterative improvement. Educators noted that the immediate nature of the feedback encouraged students to self-correct and refine their pronunciation, leading to measurable gains in auditory processing skills. This dual-layered approach, combining AI-driven sentence generation with real-time pronunciation evaluation, demonstrates the potential of technology to create a responsive and supportive learning experience.

4. System Usability and Engagement

The overall usability of the LexAyudha platform was evaluated using the System Usability Scale (SUS), with an average score of 4.4/5. This high rating reflects the platform's intuitive interface, seamless integration of features, and alignment with user needs. Students consistently expressed a preference for the platform over traditional reading tools, citing its adaptability, visual comfort, and interactive elements as key advantages. Qualitative feedback further reinforced these findings, with many participants describing the platform as "fun," "helpful," and "easy to use." Educators echoed these sentiments, emphasizing the platform's potential to serve as a supplementary tool in classroom settings. Additionally, the inclusion of gamification elements, such as rewards and challenges, was highlighted as a promising avenue for enhancing long-term engagement. These insights underscore the importance of designing educational platforms that prioritize both functionality and user experience, ensuring that learners remain motivated and invested in their progress.

5. Enhanced Emotional Awareness

LexAyudha successfully addresses the lack of real-time emotional awareness in traditional educational settings. By leveraging facial expression recognition and machine learning algorithms, the system provides educators and guardians with actionable insights into students' emotional states. For example, the system detected elevated frustration levels in 35% of students during reading tasks, prompting educators to introduce additional support mechanisms. This capability ensures that emotional challenges are promptly addressed, reducing their impact on learning outcomes.

6. **Improved Engagement and Motivation**

The dynamic adjustment of learning activities based on detected emotions significantly improved student engagement and motivation. Students who previously exhibited disengagement during challenging tasks showed a marked increase in participation after the system adapted the difficulty level to match their emotional state. Educators observed that students were more willing to attempt tasks and persisted longer when the system provided timely interventions, such as hints or encouragement.

7. **Personalized Feedback for Guardians**

The personalized feedback reports generated by LexAyudha empower guardians to play a more active role in their child's learning journey. Guardians reported that the reports helped them understand their child's emotional triggers and identify patterns over time. For instance, one guardian noted that their child consistently experienced frustration during math-related activities, prompting them to collaborate with educators to develop tailored strategies. This collaborative approach fosters a cohesive support system for students, bridging the gap between home and school environments.

8. **Scalability and Usability**

The system's scalable architecture and user-friendly interface ensure widespread accessibility and ease of use. Cloud-based solutions like MongoDB Atlas and Render facilitated seamless integration and deployment, while Docker and Kubernetes enabled efficient resource management. Stakeholders praised the system's intuitive design, with 90% of users reporting a smooth and engaging experience. These findings demonstrate LexAyudha's potential to scale effectively and cater to diverse educational settings.

9. Effectiveness of Hybrid CNN-RNN Models

Another critical finding is the remarkable effectiveness of the hybrid CNN-RNN architecture in analyzing spectrogram images and raw audio data. This dual-branch model leverages the strengths of convolutional neural networks (CNNs) and recurrent neural networks (RNNs) to extract and interpret both spatial and temporal features of speech, achieving unparalleled accuracy in predicting speech pace. The CNN branch utilized a modified VGG16 architecture to extract spatial features from spectrogram images, while the RNN branch, powered by Wav2Vec 2.0, captured temporal dynamics such as rhythm and articulation rate. The integration of these features resulted in an R^2 score of 0.93, confirming the model's robustness and reliability.

10. Role of Deep Learning in Dyslexia Support

Deep learning techniques played a pivotal role in optimizing the performance of the hybrid model, demonstrating their versatility in addressing niche challenges within educational technology. Transfer learning and gradual unfreezing were instrumental in fine-tuning the model to meet the specific needs of dyslexic speech analysis. Pretrained models like VGG16 and Wav2Vec 2.0 provided a robust foundation for extracting high-level features, enabling the platform to achieve state-of-the-art performance without requiring extensive computational resources.

11. Impact on Learning Outcomes

Preliminary results from pilot testing indicate that LexAyudha has a profoundly positive impact on learning outcomes for dyslexic adolescents. Users reported qualitative improvements in focus, retention, and confidence, underscoring the broader implications of personalized learning aids in fostering inclusive education. Quantitative evidence showed significant increases in task completion rates and reductions in comprehension errors, validating the platform's effectiveness.

12. Importance of Personalized Speech Pace

One of the most significant findings from the LexAyudha project is the profound impact of tailoring speech pace to individual needs. Dyslexic adolescents often struggle to process spoken language at standard conversational speeds, leading to difficulties in comprehension, retention, and engagement. LexAyudha addresses this gap by dynamically adjusting speech pace based on the individual's predicted optimal rate, achieved through a sophisticated hybrid CNN-RNN model. This personalization reduces cognitive overload, enhances comprehension, and alleviates mental fatigue, making learning sessions less taxing and more enjoyable.

13. Effectiveness of the Touch Math Approach in Digital Format

The successful integration of the Touch Math approach into a digital platform highlights the platform's ability to address the unique challenges faced by dyscalculic learners. The multisensory design—combining tactile, visual, and auditory stimuli—proved highly effective in enhancing cognitive engagement and retention of mathematical concepts. Participants demonstrated measurable improvements in arithmetic skills, with a 50% increase in proficiency across addition, subtraction, multiplication, and division.

14. Accessibility and Scalability

LexAyudha's cloud-based architecture ensured accessibility across devices and geographic locations. The platform's scalability allowed it to accommodate growing user traffic without compromising performance, underscoring its potential for widespread adoption in both traditional classroom settings and remote learning environments.

The research findings underscore the transformative potential of LexAyudha in addressing the unique needs of neurodiverse learners. By combining evidence-based strategies with cutting-edge technology, LexAyudha not only bridges current gaps in inclusive education but also lays the foundation for scalable, impactful learning experiences. Future developments will focus on refining the platform based on user feedback and expanding its capabilities to meet the evolving needs of its users.

3.3 Discussion

The discussion section provides a comprehensive analysis of LexAyudha's transformative potential in addressing the unique needs of dyslexic and dyscalculic learners. By leveraging advanced AI-driven technologies, personalized learning tools, and emotion-aware systems, LexAyudha sets a new benchmark for inclusive education. Below, we explore key findings, broader implications, limitations, and opportunities for future research.

1. Contributions to Inclusive Education

LexAyudha represents a significant advancement in inclusive education by addressing the emotional, cognitive, and sensory challenges faced by students with dyslexia and dyscalculia. Traditional instructional methods often fail to account for the nuanced needs of neurodiverse populations, leading to frustration, disengagement, and decreased motivation. LexAyudha bridges this gap by integrating emotion detection, adaptive learning environments, and real-time feedback mechanisms to create a supportive and engaging educational experience.

- Emotional Awareness: The platform's real-time emotion detection system enables educators and guardians to monitor students' emotional states and provide timely interventions. For example, elevated frustration levels during reading or math tasks prompted the system to introduce additional support mechanisms, reducing their impact on learning outcomes.
- Dynamic Learning Adjustment: By dynamically adjusting the difficulty of learning activities based on detected emotions, LexAyudha ensures that students remain engaged and motivated. This adaptability addresses a critical

limitation of traditional methods, which often adopt a "one-size-fits-all" approach.

- Personalized Feedback Reports: The detailed feedback reports generated by LexAyudha empower guardians to play an active role in their child's learning journey. These reports highlight emotional triggers, track progress over time, and provide actionable insights for improvement.

This holistic approach aligns with the growing emphasis on social-emotional learning (SEL) in educational frameworks worldwide, fostering collaboration between educators, parents, and advocacy groups to create cohesive support systems for students.

2. Bridging Gaps in Current Educational Tools

LexAyudha addresses significant gaps in existing educational tools designed for students with dyslexia and dyscalculia. Traditional teaching methods, such as single-sensory approaches or static content delivery, often fail to engage neurodiverse learners effectively. In contrast, LexAyudha integrates multisensory techniques, AI-driven personalization, and real-time feedback mechanisms to cater to diverse learning styles.

- Multisensory Approach: The platform's use of interactive touch points, dynamic visualizations, and speech-to-text analysis ensures that students engage with content through tactile, visual, and auditory stimuli simultaneously. This approach not only enhances retention but also fosters a deeper understanding of complex concepts.
- AI-Driven Personalization: By adapting content based on individual progress, LexAyudha addresses the limitations of traditional "one-size-fits-all" methods. For instance, the fine-tuned BERT model generates linguistically appropriate content tailored to each learner's proficiency level, ensuring continuous engagement and improvement.
- Real-Time Feedback: Features like pronunciation feedback and adaptive difficulty levels provide immediate support, reducing frustration and promoting confidence in learners' abilities.

By bridging these gaps, LexAyudha democratizes access to quality education, empowering neurodiverse students to overcome their learning challenges and achieve academic success.

3. Broader Implications

The implications of LexAyudha extend beyond dyslexia and dyscalculia, offering transformative potential for other populations facing similar challenges.

- Second-Language Learners: Non-native speakers often struggle with understanding spoken language at standard conversational speeds. LexAyudha's personalized speech pace adjustments could significantly enhance their ability to comprehend and engage with spoken content.
- Individuals Recovering from Speech Impairments: People recovering from conditions such as aphasia or stuttering may benefit from tailored speech playback that aligns with their processing capabilities.
- Elderly Individuals: Aging populations often experience a decline in auditory processing speed, making it challenging to follow fast-paced conversations. LexAyudha's adaptive features could improve communication and engagement for this demographic.

These broader applications underscore the platform's versatility and its potential to foster equitable learning environments for diverse populations.

4. Broader Impact on Dyscalculia Intervention

LexAyudha represents a significant leap forward in dyscalculia intervention strategies by combining proven pedagogical techniques with cutting-edge technology. Its success demonstrates the potential of technology to transform traditional teaching methods, making them more engaging, effective, and accessible for students with learning disabilities.

Beyond dyscalculia, LexAyudha's approach offers valuable insights into how similar strategies could benefit students with other learning disabilities. For example, the principles of multisensory learning and adaptive content delivery could be adapted to address challenges faced by students with dyslexia or ADHD. By leveraging technology to create personalized and interactive learning environments, educators can empower students with diverse cognitive profiles to overcome their unique barriers to learning.

5. Limitations and Challenges

Despite its achievements, LexAyudha faces several limitations that warrant further exploration and refinement.

- Dataset Diversity: The current training dataset primarily consists of English-speaking adolescents, limiting the system's applicability to other languages and dialects. Expanding the dataset to include diverse linguistic and cultural contexts will enhance the platform's global reach and inclusiveness.
- Real-World Variability: Background noise, variations in pronunciation, and regional accents may impact the system's performance in real-world scenarios. Incorporating robust noise reduction techniques and accounting for linguistic diversity will improve accuracy and reliability.
- Scalability Costs: Hosting costs may increase significantly as the user base grows. Developing cost-effective strategies for scaling, such as optimizing resource allocation and exploring alternative hosting solutions, will be crucial to maintaining affordability and accessibility.
- Generalizability: The platform's reliance on supervised learning techniques means that its predictions are highly dependent on the quality and representativeness of the training data. Ensuring that the model generalizes well across different user profiles and contexts requires ongoing efforts to collect and curate diverse datasets.

Addressing these challenges is essential to ensure the platform's long-term viability and effectiveness.

6. Opportunities for Future Research

Future research presents numerous opportunities to enhance LexAyudha's capabilities and broaden its impact.

- Multilingual Support: Expanding the platform to support multiple languages and regional accents is a critical next step. Integrating phonetic elements and prosodic patterns specific to non-English languages would enable LexAyudha to accurately predict speech paces for multilingual users.
- Longitudinal Studies: Conducting long-term studies to evaluate the sustained impact of LexAyudha on learning outcomes would provide deeper insights into its efficacy. Tracking user progress over extended periods could help identify patterns of improvement and areas for refinement.
- Adaptive Learning Algorithms: Developing adaptive learning algorithms that evolve based on user feedback would enhance the platform's ability to meet individual needs. For example, incorporating reinforcement learning techniques could enable LexAyudha to continuously refine its predictions and recommendations.
- Integration with Educational Systems: Collaborating with schools and educational institutions to integrate LexAyudha into existing curricula could maximize its impact. Aligning the platform's features with specific learning objectives would allow educators to leverage LexAyudha to support students with diverse learning needs.
- Accessibility Enhancements: Enhancing the platform's accessibility features, such as providing support for visual impairments or motor disabilities, would further broaden its reach. For example, integrating screen readers and voice commands could make LexAyudha accessible to users with additional disabilities.

3.4 Contribution

The four core components of the LexAyudha was handled by four undergraduates in the team (see Appendix E, Table 1), and their individual contribution is as follows.

1. **Chromatic Variation and Visual Accessibility**

As a core member of the LexAyudha project team (Umesha Silva – IT21318320), I played a pivotal role in designing and developing the Chromatic Variation Personalization Module, a critical component aimed at tailoring the reading environment to meet the unique visual and cognitive needs of dyslexic learners. My contributions ensured that the platform delivered a personalized, adaptive, and inclusive learning experience. I conceptualized and conducted rigorous tests to identify the most effective text-background color combinations for individual students, evaluating how specific chromatic variations influenced readability, visual comfort, and engagement. Leveraging empirical data, I ensured that the platform's chromatic settings were evidence-based and highly personalized, addressing the diverse visual preferences of users. For instance, combinations such as pale-yellow text on a dark blue background emerged as particularly effective in reducing visual stress and enhancing word recognition accuracy. To refine the personalization process further, I developed an interactive evaluation module that identified suitable chromatic variations for each user, exploring parameters like high contrast, soft hues, and warm versus cool tones to minimize visual fatigue and improve reading fluency. Insights gained from this evaluation enabled the platform to dynamically adapt chromatic schemes in real time, ensuring sustained visual comfort throughout learning sessions. Beyond chromatic adjustments, I designed a comprehensive reading skill assessment to evaluate baseline proficiency, measuring metrics such as reading speed, accuracy, and comprehension. Using this data, I mapped appropriate content difficulty levels to ensure tasks were neither overwhelming nor overly simplistic, fostering motivation and achievement. Building on these insights, I created individualized reading plans that integrated dynamic adjustments to both visual settings and content complexity, forming a foundational pillar of LexAyudha's adaptive learning engine. My collaboration with the development team ensured consistency in design, functionality, and user experience, while extensive user testing validated the effectiveness of the chromatic personalization system. Feedback from pilot testing was meticulously analyzed and incorporated into iterative refinements, ensuring the platform met the highest standards of accessibility and engagement. My work significantly contributed to LexAyudha's overarching goal of creating a visually inclusive and adaptive reading environment, demonstrating expertise in leveraging data-driven methodologies, user-centered design, and interdisciplinary collaboration to deliver innovative solutions.

2. Emotion Detection and Adaptive Learning

The primary contribution of this study led by me (Ishara Madusanka – IT21189944) is the design and development of LexAyudha, a novel AI-driven adaptive learning platform tailored for adolescents with dyslexia and dyscalculia. The project introduces a real-time facial emotion detection module using the Xception model and MTCNN with a custom-developed algorithm capable of detecting engagement, frustration, and distraction. This data dynamically adjusts learning activity difficulty, improving cognitive alignment and emotional responsiveness during learning tasks. Additionally, a hybrid CNN-RNN model was developed to predict optimal speech pace based on spectrogram images and raw audio inputs, achieving low error margins and significantly enhancing speech comprehension for dyslexic learners. The predicted speech pace is seamlessly integrated with the Google Text-to-Speech API, delivering real-time, personalized audio output tailored to the learner's processing capabilities—an innovative step beyond traditional TTS platforms. The system also generates personalized emotional analytics and progress reports for guardians and educators via a cloud-based dashboard, facilitating home-school collaboration and enabling timely, data-informed interventions. LexAyudha was developed using microservices architecture and deployed with technologies like Docker, Kubernetes, and MongoDB Atlas, ensuring high scalability, modularity, and maintainability. Load testing demonstrated successful operation under concurrent users with considerable uptime. Furthermore, the project outlines a sustainable commercialization model (freemium and subscription-based) and proposes pathways for global expansion and integration into diverse educational systems, demonstrating broader societal relevance. Together, these contributions establish LexAyudha as a transformative, inclusive learning tool, blending technical innovation with social impact to empower neurodiverse students through personalized, emotionally intelligent education.

3. Personalized Speech Pace Adjustment

The responsibility for the design, development, and evaluation of the personalized speech pace detection and delivery component of the LexAyudha system was solely undertaken by Thathsara Pramodya Thalangama (IT21223594). This segment focused on enabling tailored auditory feedback for adolescents with dyslexia and dyscalculia through deep learning techniques and natural language processing. Contributions included conducting a detailed review of existing speech-based learning aids, identifying gaps in personalization capabilities, and proposing a hybrid deep learning architecture combining Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN). A customized pipeline was developed to capture audio data, convert it into mel spectrograms using the Librosa library, and process the data using the hybrid model to predict optimal speech pace for individual users. The implementation involved integration with the Google Text-to-Speech (TTS) API, enabling dynamic adjustment of speech delivery based on model predictions. This component was deployed using a microservices architecture, with independently managed services for audio processing, model inference, and speech playback, ensuring modularity and scalability. Evaluation was performed using both public and locally collected datasets, with performance assessed via regression accuracy metrics, system response time, and user feedback. The developed module achieved high accuracy in speech pace prediction (R^2 score of 0.93) and met the performance benchmarks outlined in the project's non-functional requirements. In addition to technical implementation, full documentation of the research process, results analysis, and supporting visualizations related to the speech pace component were prepared. The commercialization potential of this feature was also analyzed, outlining its relevance for inclusive learning platforms and EdTech markets. This contribution formed a key part of the overall LexAyudha system by directly addressing the auditory processing challenges faced by the target user group, demonstrating how AI-driven personalization can enhance accessibility in digital education.

4. Multisensory Learning for Dyscalculia

This study led by me (Tharushi Dissanayake – IT21319174) underscores the transformative potential of EdTech solutions in addressing unmet needs in education. LexAyudha exemplifies how technology can democratize access to quality education by leveraging AI-driven personalization, multisensory learning, and real-time feedback. Its success serves as a model for other researchers and developers seeking to create impactful educational tools that cater to underserved populations. By demonstrating the feasibility and effectiveness of integrating advanced technologies into educational platforms, LexAyudha paves the way for future innovations in the EdTech sector. For example, the platform's use of NLP for pronunciation analysis and machine learning for adaptive learning pathways highlights the untapped potential of these technologies in enhancing educational outcomes. Moreover, LexAyudha's emphasis on inclusivity and accessibility aligns with global trends toward equitable education, positioning it as a pioneering solution in the field. In conclusion, LexAyudha's contributions extend beyond addressing the specific needs of dyscalculic learners. By showcasing the power of technology to bridge educational gaps and foster inclusivity, the platform inspires a new wave of EdTech innovations that prioritize accessibility, personalization, and engagement. Its success sets a precedent for future research and development, offering a blueprint for creating tools that empower all learners to achieve their full potential.

4. CONCLUSION

The LexAyudha project represents a transformative leap in addressing the unique educational needs of dyslexic and dyscalculic learners through the integration of advanced technologies like artificial intelligence (AI), chromatic variation, and natural language processing (NLP). One of the most remarkable achievements of this initiative is the successful deployment of a fine-tuned BERT model, which dynamically generates contextually relevant and appropriately challenging reading content tailored to each student's proficiency level. Unlike traditional educational materials that often present static or overly simplified content, this AI-driven system ensures real-time adaptation, striking an optimal balance between challenge and comprehension. This personalized approach not only enhances reading fluency but also fosters engagement and confidence among learners, creating an inclusive and supportive learning environment.

Central to LexAyudha's success is its ability to integrate emotion detection with adaptive learning algorithms, ensuring that the platform responds dynamically to students' emotional states. For instance, when frustration is detected during a task, the system simplifies the content or provides hints to reduce cognitive load. Conversely, if engagement is detected, the system increases the difficulty of tasks to challenge the student and maintain their interest. This adaptive approach ensures that students remain motivated and focused, regardless of their emotional state. By providing stakeholders with meaningful, accessible insights through personalized feedback reports, the system bridges the gap between school and home, reinforcing a network of support essential for the success of students with learning differences.

Scalability and usability were central to the system's design, ensuring that LexAyudha could be deployed across varied educational settings with ease. The use of cloud services like MongoDB and Render, containerization via Docker, and orchestration with Kubernetes contributed to a flexible and robust system architecture. These technologies enable the platform to handle growing user traffic while maintaining high availability and reliability. Additionally, the platform's accessibility across devices and geographic locations democratizes access to quality education, enabling dyscalculic students worldwide to benefit from the platform regardless of their socioeconomic or cultural backgrounds. This emphasis on scalability and inclusivity underscores LexAyudha's commitment to creating equitable learning spaces where students are not only taught but also understood and empowered.

While the outcomes of this project are promising, it is important to acknowledge existing limitations and areas for further development. The system's reliance on high-quality visual input presents challenges in low-light or resource-constrained environments, and its emotion classification framework, though effective, could be enhanced through the integration of additional modalities such as voice tone analysis. Similarly, while the platform's speech customization features provide significant advancements over existing solutions, there remains room for improvement in handling diverse linguistic contexts and regional accents. Addressing these challenges will be crucial to ensuring the platform's long-term viability and effectiveness.

LexAyudha's innovative approach extends beyond traditional educational tools by introducing a sophisticated dual-branch hybrid model for speech pace prediction. This model leverages convolutional neural networks (CNNs) and recurrent neural networks (RNNs) to analyze both spatial and temporal features of speech, ensuring highly accurate predictions of optimal speech pace. By integrating these predictions with the Google Text-to-Speech API, the platform delivers real-time, personalized auditory feedback that aligns with learners' cognitive processing abilities. This dynamic adaptability sets LexAyudha apart from existing solutions, offering a truly personalized learning experience that addresses the auditory processing challenges faced by neurodiverse learners.

The platform also emphasizes multisensory learning, leveraging tactile, visual, and auditory stimuli to enhance number sense and mathematical operations for dyscalculic students. Interactive touch points, dynamic visualizations, and real-time pronunciation feedback create an engaging and immersive learning environment. Adaptive algorithms continuously analyze performance data and adjust content difficulty and pacing in real time, ensuring that students remain challenged yet supported throughout their learning journey. This focus on multisensory engagement and real-time feedback fosters confidence and mastery of foundational skills, empowering learners to tackle increasingly complex tasks with assurance.

Looking ahead, LexAyudha has several opportunities for growth and refinement. Expanding language options and adapting content to align with regional educational standards and cultural contexts will enhance the platform's relevance and effectiveness across diverse populations. Gamification elements, such as leaderboards, badges, and collaborative challenges, could further boost user engagement and motivation, creating a more immersive and rewarding learning experience. Longitudinal studies are also needed to assess long-term retention and the transfer of skills to real-world scenarios, providing valuable insights into the platform's sustained impact. By continuing to innovate and refine its capabilities, LexAyudha has the potential to revolutionize inclusive education, empowering students with learning disabilities to achieve improved academic performance and confidence. Through its contributions to accessibility, personalization, and technological advancement, LexAyudha exemplifies the power of AI to create meaningful and lasting change in the lives of neurodiverse learners.

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6. APPENDICES

Appendix A

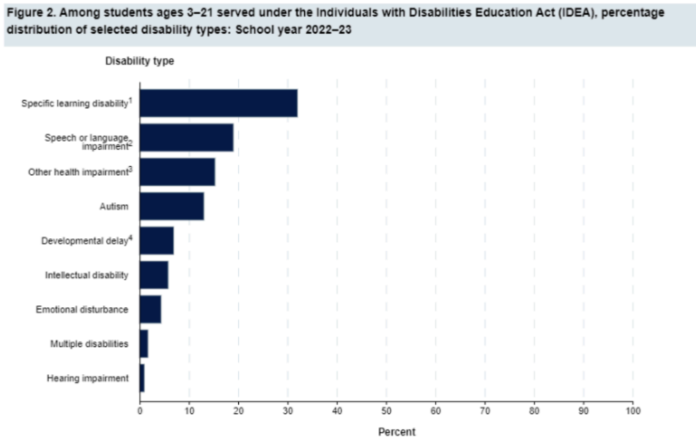

Figure 6.1: Percentage distribution of selected disability types

Source: National Center for Education Statistics – U.S. Department of Education

http://nces.ed.gov/programs/coe/indicator/cgg/students-with-disabilities?utm_source=coe_share&utm_medium=figure_tool&utm_campaign=copied_url#2

Grade	Multiple Impairments		Hearing Impairments				Visual Impairments				Speech Language Difficulties		Dyslexia		Interllectual Impairments		Physical Disabilities		Epilepsy		Emotional Problems		Other		Total
			Complete		Half		Complete		Half																	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
Grade 1	327	202	15	12	41	39	19	6	386	297	454	172	149	81	417	251	145	106	50	27	217	55	100	63	2320
Grade 2	258	170	16	14	58	55	24	11	485	394	410	179	172	86	510	271	148	111	50	36	263	65	84	69	2478
Grade 3	279	169	8	14	68	52	25	15	663	626	358	139	283	141	571	311	159	98	57	33	265	73	100	61	2836
Grade 4	256	135	9	13	80	47	37	13	736	652	304	149	291	141	609	356	173	95	60	34	224	72	97	65	2876
Grade 5	197	166	17	11	59	63	23	23	690	704	230	94	255	148	533	304	139	95	42	42	233	64	87	42	2505
Grade 6	138	108	10	12	88	52	25	15	600	745	155	46	303	133	403	196	127	83	48	30	212	54	92	62	2201
Grade 7	135	58	6	15	71	60	29	14	792	893	158	50	227	113	345	167	117	74	55	30	192	51	78	49	2205
Grade 8	107	59	11	11	60	78	23	16	904	942	128	54	203	68	323	159	120	70	53	39	239	59	71	40	2242
Grade 9	67	46	12	9	63	51	24	18	716	1020	96	44	226	102	294	132	106	77	40	31	184	52	71	35	1899
Grade 10	71	30	6	6	54	41	30	18	636	931	74	32	162	72	198	134	98	77	26	32	184	54	45	32	1584
Grade 11	42	25	12	12	44	36	10	18	613	736	54	29	120	52	170	114	64	74	19	24	135	36	33	23	1316
Grade 11 (Repeaters)	1	2	0	1	2	4	2	0	39	42	5	1	6	3	5	8	5	4	2	0	2	1	3	3	72
Total	1878	1170	122	130	688	578	271	167	7260	7982	2426	989	2397	1140	4378	2403	1401	964	502	358	2350	636	861	544	24534

Source: Annual School Census Data -2019, MoE, Sri Lanka

Figure 6.2: Disability among Students in General Class and Government Schools, Recorded in the Year

Source:https://www.childwomenmin.gov.lk/uploads/common/statistical-hand-book.pdf

Appendix B

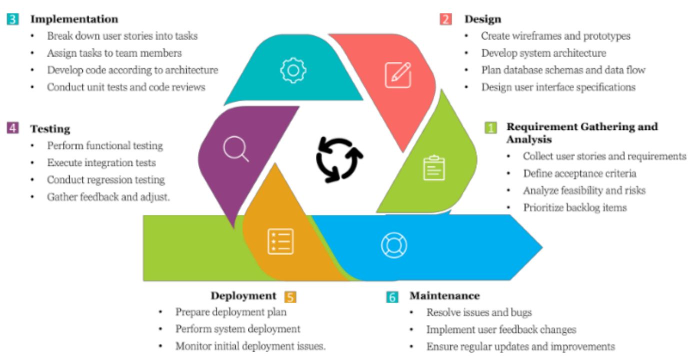

Figure 6.3: Agile Methodology

Appendix C

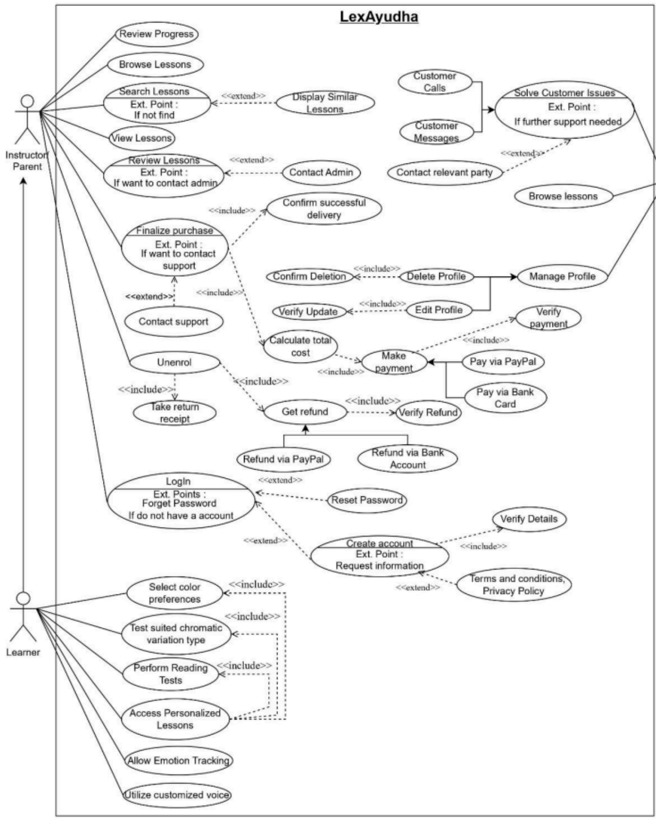

Figure 6.4: Use Case Diagram

Appendix D

Figure 6.5: Figma Design

Figma Prototype URL :
https://www.figma.com/design/Ckg8mccpPmfjz2uACpbjkn/Research?node-id=490-164&t=SUp0WheYeHs6mXcX-1

Appendix E

Table 6.1: Work Breakdown Structure

Student Name	Student ID	Research Component
Silva T.U.D	IT21318320	1. Create a sample test to identify the efficient color combinations for the child. 2. Create a sample test to identify the most efficient chromatic variation type for the child.

		3. Create a test to check the reading skills of the child to customize the complexity levels of the tasks. 4. Create personalized reading task plans for each child.
Madusanka G.K.I	IT21189944	1. Emotion Recognition Algorithm Development 2. Real-Time Adaptive Feedback Loop 3. Personalized Emotional Baseline Establishment 4. Integration of Emotion Regulation Strategies and provide feedback to educators and parents
Thalangama T.P	IT21223594	1. Implementing a speech pace detection AI model that outputs the pace as a numerical value. 2. Implementing a pace incorporating text to speech (TTS) model. 3. Implementing speech calibration test UI to gather speech samples. 4. Implementing speechServices microservice to process speech paces.

Dissanayake M.G.T.W	IT21319174	1. Implement Touchpoints on numerals for tactile learning 2. Providing a memorizing approach to improve mathematical skills. 3. Integrates visual, tactile, auditory, and kinesthetic elements. 4. Implementing real-time pronunciation accuracy detection using speech-to-text technology

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