Adaptive Multi-model Machine-Learning and AI Systems for Strengthening the Emotional Well-being of Children with Trisomy 21

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***Abstract*- This research study demonstrates a web application designed to strengthen children's cognitive skills and emotional well-being with Trisomy 21, utilizing interactive and tailored tools. Trisomy 21 is a chromosomal anomaly caused by an extra copy of the 21st chromosome, which affects a child's cognitive development. Despite the technological evolution, a significant gap persists in accessibility and multimodal approaches that meet the unique needs of children with Trisomy 21. The main objective of the research study was to develop a multi-model web-based application, "Mockley kids," customized for children with Trisomy 21 that helps to enhance their cognitive skills and emotional well-being. The developed system integrated an artificial intelligence (AI) powered voice assistance to enhance communication, and learning, an emotion-based music recommender to enhance emotional well-being and provide a calm and uplifting environment, a text-based bot to enhance literacy skills and communication, and interactive games "Who am I?", "Tic-tac-toe", "Simon-says" to increase attention span, decision making, which are tailored to enhance their cognitive skills and emotional well-being. The development and implementation of this project follows a structured process aligned with Agile project methodology. To evaluate the "Mockley kids" system's impact on children with Trisomy 21, 16 children who were diagnosed with Trisomy 21 engaged with the system for 20 minutes for a week, under the supervision of 8 professionals, including 3 speech therapists, 3 occupational therapists, and 2 educators. Overall results show that the children were excited to integrate with the system and enjoyed the system. Both the professionals and the parents stated that they had evident noticeable improvements in cognitive abilities, including enhanced communication, memory recall, enhanced attention span, and improvements in emotional well-being.**

***Keywords*- Trisomy 21, Assistive Technology, Artificial Intelligence (AI), Cognitive development, Emotion-based music recommender**

I.INTRODUCTION

Trisomy 21, also known as "Down syndrome," is a common genetic disorder caused by a chromosomal anomaly that leads to intellectual disabilities and developmental delays [1]. Children with Trisomy 21 often face diverse challenges, including communication, social engagement, and emotional challenges. Eddaoudi et al. have pointed out the psychological, familial, and social challenges experienced by the parents of children with Trisomy 21 [2], and Er-rida et al. highlighted the challenges faced by parents of children with Trisomy 21 while providing education to their children at different age levels [3], emphasizing the need for tailored and more inclusive support beyond clinical support.

Even though technological transformation provides different innovative tools to improve learning, communication, and emotional engagement for children with intellectual disabilities, Shahid et al. highlight the gap in tailored applications for individuals with special needs, pointing out the need for further research on emerging technologies [4]. Fritz et al. highlight how technology enhances the independence of children with Trisomy 21 and helps families adapt to support their daily functions [5].

Gemma et al. demonstrate that music is beneficial for individuals with Trisomy 21 [6], and Steinberg et al. demonstrate that integrating music into a daily routine shows a positive impact on emotional bonding and communication [7]. Kasuya-Ueba et al. further supported and highlighted the ability of music-based intervention in enhancing emotional bonding, attention, and engagement [8].

Mateos-Sanchez et al. introduced "CapacitaBOT," a mobile chatbot tailored for children with intellectual disabilities. Research aimed to enhance social skills through interactive learning. Furthermore, this study highlights the effectiveness of AI-powered tools in education and therapy, especially during periods of social isolation like the COVID-19 pandemic [9]. Despite the valuable outcome from the CapacitaBOT, it primarily focuses on text-based chatbot interactions with limited customization for children with Trisomy 21 and is only

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focused on social skills and education. In contrast, the "Mockley kids" is a web-based system that focuses on roviding emotional, social, educational, and cognitive support with a customizable experience focusing on different levels ofTrisomy 21 and different age levels. Panceri et al. introduced the "MARIA T21," a socially assistive robot, focused on improving the psychomotor and psychosocial skills in children with Trisomy 21 and autism spectrum disorder (ASD). A series of game-based on behavioral psychology was integrated into "MARIA T21" to prove that child-robot interactions can significantly strengthen the engagement [10]. Accessibility of the MARIA T21 is limited by specialized hardware and focused on providing social skills, motor skills, and cognitive skills. In contrast, "Mockley kids" addresses these gaps by offering a fully digital, customizable support focusing on emotional, social, educational, and cognitive aspects. Costanzo et al. introduced "Talkitt", an AI-powered mobile application developed to improve communication of individuals with Trisomy 21. Through a six-month intervention, the application depicts notable enhancements in linguistic skills, suggesting that AI-based augmentatives and Alternative Communication (AAC) tools foster better communication [11]. Although "Talkitt" provides a powerful speech recognition solution to aid individuals with unintelligible speech scope is limited to communication. "Mockley kids" system focuses on providing both emotional and cognitive support with a customizable environment for different levels of children with Trisomy 21.

Kokol et al. shows a collective study of 145 Studies on game-based interventions for children with developmental disabilities. This study noticed a positive outcome in areas such as anxiety reduction, emotion recognition, and rehabilitation [11].

Despite the presence of technological interventions for children with Trisomy 21, a gap persists in the accessibility of existing systems and the absence of multimodal, tailored interventions that provide combined support of cognitive and emotional aspects. Existing systems often focused on specific aspects such as emotional well-being or education, without addressing the comprehensive emotional and cognitive needs of children with trisomy 21. This research study intends to bridge the gap by developing an adaptive multimodal web-based application called "Mockley kids", integrated with an AI-powered voice assistance, text-based bot, emotion-based music recommender, and interactive games to strengthen both cognitive skills and emotional well-being. This research study focuses on the key research question: how a customized multimodal web application integrated with AI-powered voice assistance, text-based bot, emotion-based music recommender, and interactive games strengthens the emotional well-being and cognitive skills of children with Trisomy 21. The primary aim of this research study was to develop an adaptive, multimodal web application that strengthens the cognitive skills and emotional well-being of children with Trisomy 21. The research objectives include developing a web application integrated with an emotion-based music recommendation model, voice assistance feature, text-based bot, and interactive game features, developing a responsive and interactive user interface, and testing the system's efficiency.

II.SYSTEM DESIGN

The developed system is a multimodal web application designed to enhance cognitive skills and provide emotional support for children with Trisomy 21 through a modular integration of several advanced and customized technologies. The developed system includes an AI-powered voice assistant, an emotion-based music recommender model, a text-based bot, interactive games "Who am I?", "Tic-tac-toe", and "Simon says" games. The system adopts a client-server model with the front end built with React.js and the backend developed with Python using Flask to manage API endpoints. AI-powered voice assistance uses speech recognition libraries to convert voice inputs to text, processes through a server, and returns the voice output using text-to-speech tools such as gTTS and Pydub. The emotion-based music recommender model captures the real-time emotions using webcam, and the captured image passes through a convolutional neural network (CNN) developed with Keras and TensorFlow, and OpenCV and trained using the FER-2013 (Facial Expression Recognition 2013) data set, which contains 7 different emotions (angry, disgust, fearful, happy, neutral, sad, and surprised). Upon emotion detection, the recommended songs list is displayed as a JSON object to the frontend. "Who am I?" and "Hangman" games were developed using Python Flask for the backend and React.js for the frontend, communicating through APIs. The games "Simon says" and "Tic Tac Toe" were implemented using React.js and React hooks for state management. The text-based bot generates the responses using the "Gorq" API. AI-powered voice assistance generates AI-powered responses using the Gemini API. Data was managed using CSV files, and the Pandas library and environment file were used to store API keys securely. The system architecture ensures modularity, responsiveness, and scalability, enabling and ensuring the smooth integration of diverse modules with diverse technologies to make the systems more efficient and customized to meet the unique needs of children with Trisomy 21.

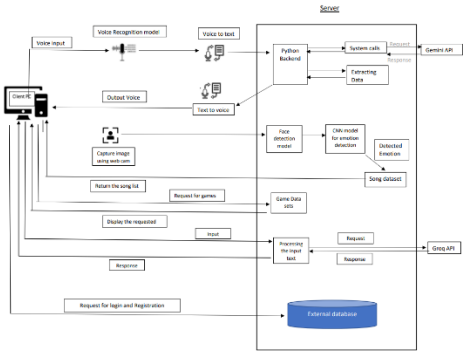

Fig. 1. Software Architectural Diagram

III.METHOD

A. System Evaluation

An observational evaluation was conducted with 16 children who were diagnosed with Trisomy 21 at a rehabilitation hospital, Sri Lanka. Each child engaged with the system for 20 minutes per day for a week. Sessions were conducted under the supervision of 8 professionals, including 3 speech therapists, 3 occupational therapists, and 2 special educators.

- Data Collection

Data collection was conducted using a structured questionnaire designed to gather feedback from both the parents of children who were involved in the evaluation sessions and professionals who supervised the sessions. The questionnaire assessed multiple dimensions, including cognitive support, emotional support, impact on motor skills accessibility, user friendliness, and overall effectiveness and satisfaction with the system. All collected data were analyzed to examine the effectiveness of the system in strengthening emotional well-being and cognitive skills, accessibility, useability, and aspects to enhance the system. Additionally, observational notes were collected from the professionals about the system for future enhancements.

IV.RESULTS

A. Evaluation of Professionals' Perspective

Professionals stated that the web application provides long-term benefits for children with Trisomy 21 in terms of cognitive development and emotional well-being. On a 5-point scale, the system received an average of 3.5 for improving memory recall, 4.13 for the capability to enhance the attention span, 2.88 for improving problem-solving skills, 3.75 for improving communication and comprehension skills, and 3.63 for enhancing decision-making and logical thinking. Lastly, 3.00 for enhancing social interaction. Furthermore, professionals commented that gamified models stimulate children's learning, leading to cognitive development [11]. Emotionally, the system was significantly effective. Professionals rated the system with 4.75 for providing emotional support, evidencing that music provides emotional support and an uplifting environment [6].

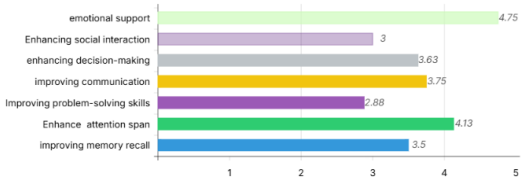

Fig. 2. Analysis of professionals' comments (Rating out of 5).

B. Evaluation of Parents' Perspective

Most parents commented that their children showed a strong interest in interactive games. 56.3% stated that they were deeply captivated, while 25% were moderately interested and 18.8% showed a mild interest, evidence that game-based intervention improves the emotional well-being of children with Trisomy 21 [11].

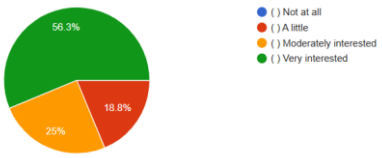

Fig. 3. Evaluation of interest in engaging with games

87.5% of parents commented that children were actively interacting with the AI-powered chatbot and revealed that this feature improves cognitive skills and emotional well-being of children with Trisomy 21. Furthermore, 100% of the respondents commented that their children show emotions while interacting with the chatbot, evidencing a positive impact on emotional well-being. 93.7% of parents declare that AI-powered chatbot encourages their child to communicate more than usual [9]. Among them, 25% of the children show significant improvements in communication, while 43.5% show notable improvements. 93.8% of parents declared that children learn new words while interacting with the chatbot.

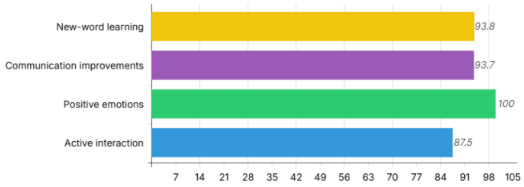

Fig. 4. Evaluation of AI-chatbot interaction

Moreover, 18.8% of parents strongly declare that the emotion-based music recommender feature improves their child's mood, and 62.5% declare a notable enhancement, while 18.8% declare a slight enhancement. Furthermore, the data collected through the questionnaires reveals that 100% of the children enjoyed the music, confirming that music therapy improves the emotional well-being of children with Trisomy 21[8].

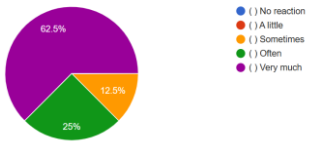

Fig. 5. Evaluation of showing emotions while interacting with the music recommender

The application appears to have a positive influence on cognitive skills enhancement. 93.7% of parents remarked that after system engagement, children were able to recognize and recall system interactions, such as words, phrases, and instructions. Furthermore, after interacting with the application, children show more interest in problem-solving and answering questions.

V.CONCLUSION

A. Findings of the Study

The "Mockley kids" application shows a significant capability in strengthening the emotional well-being and cognitive skills of children with Trisomy 21. According to the professionals, the key features AI-powered chatbot, emotion-based music recommender, and interactive games were the features enjoyed by the children the most. Furthermore, the system enhances children's memory recall, attention span, problem-solving skills, and language and communication comprehension. Many professionals and parents commented on significant improvements in children's ability to identify emotions, problem-solving skills, and learning new words and phrases. The emotion-based music recommender feature was compatible with a child's mood and effectively provided a calm and uplifting environment. Several professionals declared confidence in the application's long-term benefits in strengthening cognitive skills and emotional well-being, making the system an invaluable tool in the therapeutic environment.

B. Limitations of the Study

Although the web application is an invaluable tool for children with Trisomy 21, certain limitations should be acknowledged. These limitations might affect the generalizability of the results and the highlighted areas for future enhancements and research. Several professionals declared that to observe a 100% accurate and measurable outcome, a minimum of 3 months' period is required, while this study covers a limited timeframe. The system lacks a progress tracker, making it challenging to obtain an accurate result over time. Additionally, the system was developed using English as the key language, creating a gap in accessing the application for children who speak other languages.

C. Future Work and Recommendations

To enhance the effectiveness of the web application, integration of a built-in progress tracker and detailed dashboard is needed to accurately evaluate the progress. Implementing multi-language support to bridge the gap in accessibility. A collaborative feature to interact with peers within the system will enhance the value of the system. Furthermore, a one-week evaluation period limits the ability to assess the accurate long-term effects of the system, so future studies need to extend 1-3 months with pre-/post-assessment and a control group and need to be focused on multiple sites to validate and generalize findings.

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ETHICAL STATEMENT

This study did not collect or store any sensitive or health-related data from the participants. Only the basic account information, including usernames, email addresses, and passwords, was required and stored during the study. Prior to the evaluation, informed consent was obtained from the parents/guardians of all the participants to ensure ethical compliance.

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