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SignMath: Enhancing Mathematical Skills for Hearing-Impaired Students through Interactive Sign Language Learning

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Abstract **- This research paper explores the development and impact of SignMath, a groundbreaking web application designed to address the unique challenges faced by deaf children in their mathematics education. With a significant population of deaf children and a prevalence of illiteracy, there is an urgent need for inclusive educational solutions that cater to their specific needs. SignMath integrates sign language, machine learning, and interactive learning materials to create an accessible and engaging mathematics learning environment. By leveraging visual aids, personalized learning features, and the seamless integration of sign language with mathematical concepts, SignMath aims to improve numeracy skills and promote inclusivity for deaf children in primary education. The paper discusses the design and development process of SignMath, highlighting its innovative features and pedagogical approach. Furthermore, an evaluation of Sign Math's effectiveness and usability is presented, showcasing its potential to enhance mathematical understanding, and learning outcomes for deaf children. The research paper concludes by emphasizing the significance of SignMath in promoting equitable access to quality mathematics education and fostering the educational success of deaf children in Sri Lanka.**

Keywords: deaf children, hearing impaired students convolutional neural networks, mathematics education, sign language, interactive learning materials, inclusivity, primary education.

I. INTRODUCTION

The development of automatic recognition systems for sign language gestures has the potential to significantly improve communication for deaf students. These systems can effectively break down and augment existing communication barriers [1]. Hearing-impaired students often face significant obstacles in acquiring mathematical skills due to the reliance on spoken language in traditional mathematics instruction. Incorporating interactive sign language learning has emerged as a promising strategy to overcome this problem and increase inclusion in mathematics education [2].ha

Among the objectives of learning mathematics in school, the importance of being able to understand mathematics is included. Deaf students use sign language to express complex concepts and thoughts [3]. Teachers can better enable deaf students to access and understand math concepts by using sign language as a medium for math instruction. Sign language is interactive and provides a dynamic learning environment so students can gain a deeper understanding of mathematical concepts[4]. Students can have a deeper comprehension of mathematical concepts since sign language is interactive and offers a dynamic learning environment.

This study aims to explore how teaching interactive sign language to DHH students can improve their mathematics abilities[5]. The results of this study will promote inclusive mathematics instruction for young kids who are hard of hearing. There are many benefits to including sign language in early mathematics training. First, it makes use of the visual modality, which is the main mode of communication for people with hearing loss [3]. Primary pupils can learn abstract mathematical topics in concrete ways by using visual representations like charts, diagrams, and manipulative [6], which promotes their understanding and engagement. Second, sign language encourages peer learning, collaboration, and problem-solving among students by facilitating communication and engagement.

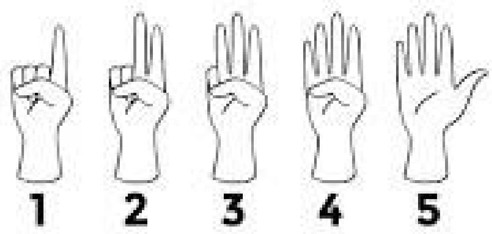

Figure 1: Sign language signs for the numbers 1 to 5

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II. LITERATURE REVIEW

The education of DHH students poses unique challenges, particularly in the acquisition of mathematical skills[7]. Traditional mathematics instruction heavily relies on spoken language, which can present significant barriers for these students. Researchers and educators have investigated the use of interactive sign language learning as a way to improve mathematical skills for children who are deaf in order to address this problem and advance inclusive mathematics education[6]. In order to improve the mathematics skills of students who are hearing-impaired, interactive sign language learning has been shown to be successful[8]. Educators have developed approaches to support DHH students in mathematics, including visual aids, manipulative, and written materials. They also use curricular and assessment modifications, real-world situations, technology, and tailored instruction to meet the unique needs of hearing-impaired students. [9]

Two studies utilized CNN architecture to recognize sign language gestures from input images. In the study focused on Sri Lankan Sign Language, an accuracy of 94.22% was achieved on a publicly available dataset, while a similar dataset yielded an accuracy of 98.4%[10][11]. The latter study further validated the effectiveness of the approach by implementing it in real-time using a webcam, demonstrating its capability to recognize American Sign Language (ASL) gestures in real-time. Both studies compared their approach to state-of-the-art techniques and reported superior accuracy results[3]. The effects of interactive sign language learning on DHH students' mathematics abilities have been studied in a number of research projects. This research looked at the usefulness of interactive sign language activities, such as conversations, games, and hands-on manipulative exercises, in fostering mathematical comprehension and engagement[4][12]. According to research interactive sign language learning improves mathematical reasoning, problem-solving skills, and collaboration capacities among hearing-impaired pupils. Additionally, it has been demonstrated that interactive sign language learning enhances students' learning and retention of mathematical terminology.

Basic mathematics operations and number patterns, which is a vast and intriguing area of mathematics, have a significant psychological impact on developing higher critical thinking, cognitive, and mathematical reasoning skills in primary school children[4]. It is recommended to include number patterns as much as possible when teaching mathematical concepts to primary school children. “Recent research has found that young children's ability to spot mathematical patterns can predict later mathematical achievement[12]

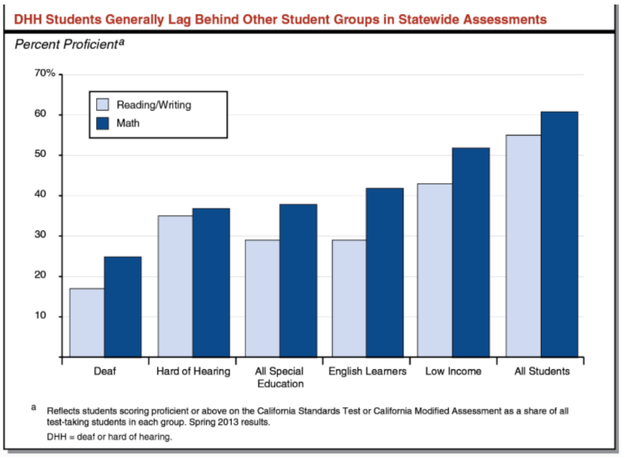

Figure 2: Scoring proficiency of students of different groups with different conditions

The Process of teaching mathematics to primary school DHH children is quite challenging. It has been identified that they lag behind their sighted peers in mathematical skills [6]. It has been found that disabilities in hearing have no significant effect on brain development and intellectual capacity; therefore, this delay is mainly due to failures in the teaching process, which is highly affected by the lack of auditory communication. Strengthening visual communication in their learning process is the potential solution to overcome the failures in auditory communication [2][8]. Utilizing graphical visualization methods and encouraging activity-based learning supported by modern technology can be used as key techniques to minimize these communication barriers.[12] In addition, DHH students can be encouraged to self-learn by providing a user-friendly GUI (Graphical User Interface) associated with ASL and an appropriate E-learning environment.[3]

Continuous support, attention, and guidance are essential in the learning process of deaf children. Their individual strengths and weaknesses should be identified, and the learning process should be personalized and updated accordingly [5]. Simultaneously, promoting independence, encouraging them to take on new challenges, and praising and acknowledging their triumphs are important for improving their confidence and self-esteem to establish a quality learning environment [13].

III. RESEARCH METHODOLOGY

The purpose of this research is to develop a tool that can help in the learning of mathematics of deaf children. The Knowledge Inspired Computing (KIC) and Computational Linguistics (CL) foundations of the system. Design an interactive learning environment for teaching numbers, basic mathematical operations, color and shape identification, and basic currency notes, the application should also calculate

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simple units and measurements and explain numerical patterns. A deep understanding of the mathematics curriculum for elementary deaf students is critical to designing effective learning aids. Knowledge of sign language is essential to represent mathematical concepts using hand signs accurately[6]. The web application requires the integration of machine learning algorithms to facilitate mobile application development and hand sign display. The use of machine learning algorithms will also be useful in analyzing student performance data to provide personalized feedback and recommendations for improvement [9]. According to the data requirements, the system consists of a database to store the information of the students, their progress, and evaluations. The data will also be used to train machine learning algorithms to better understand the learning patterns of hearing-impaired children. This research will provide an opportunity to advance the field of mathematics education by integrating technology and machine learning for hearing-impaired students.

Several technologies have been selected to support the implementation of interactive learning environments for teaching and evaluation of Sri Lankan Sign Language. These technologies involve TensorFlow, Flutter, Node.js, Python, Firebase, and API integration. The web app was created using Flutter, providing deaf students access to interactive classes, quizzes, and progress-monitoring tools. In this research, machine learning algorithms that analyze student performance data, provide individualized feedback, and evaluate the effectiveness of educational materials are developed and integrated using TensorFlow.Node.js Server-side scripting and networking features are made possible via JavaScript. It can be used to create backend infrastructure and manage server-side operations like data processing, storage, and retrieving. The programming language is Python. In this research, Python is used for a variety of activities including data preprocessing, creating machine learning models, and incorporating TensorFlow.

Evaluations, progress data, and student information are all managed and stored using Firebase. The system is perfect for monitoring and evaluating student performance due to its real-time database capabilities and simple interaction with web applications. The research project can use external services and resources by integrating APIs (Application Programming Interfaces). Students' learning experiences can be improved by including relevant educational resources like mathematical equations, images, videos, sample quizzes, and more through APIs. Access to external resources from within a web application is made simple through API integration. By integrating these technologies, can use machine learning, web application development, data storage, and external resources to create an interactive learning environment that addresses the specific needs of deaf students learning in Sri Lankan Sign Language. This paper divided the whole system into four sub-steps. These are Data collection, Model Building, model training, and Real-time prediction.

In the preprocessing step, the preprocessed dataset was divided into training, validation, and testing sets. The training set was used to train the model, the validation set for hyperparameter tuning, and the testing set for evaluating the final model's performance [2]. We preprocess all images that are present in the dataset. First, we complete the resizing of the video and all the photos (to 160x120 pixels). We divided the dataset into 85/15 ratios after constructing the label in order to generate training and testing datasets. Here, the testing dataset is utilized to validate the model after it has been trained using the training dataset.

The data collection process is done using a camera. These pictures and videos include various poses and actions. Furthermore, images and videos were captured at different sizes to provide a detailed representation of sign language gestures. To assess the accuracy of participants' answers, hand signals were captured in real-time by the training models via webcam. To ensure consistency, data collection sessions were conducted in a controlled environment. Each image or frame collected from the videos is annotated with bounding boxes around sign language gestures. Also, the collected datasets were reviewed for any inconsistencies or errors. To ensure the reliability of the data set, erroneous annotations or low-quality samples are removed, and increasing the amount of dataset used can improve the variability of the data set. were applied. These techniques include random rotation, scaling, flipping, and translation of the images[14][15]. Augmentation helps the model learn to recognize sign language gestures from various perspectives.

Data splitting: The preprocessed dataset was divided into training, validation, and testing sets. The training set was used to train the model, the validation set for hyperparameter tuning, and the testing set for evaluating the final model's performance.

Overall, these methods collectively aimed to improve communication and accessibility for individuals with hearing impairments. They offered diverse ways to convey and comprehend sign language in various contexts. Different CNN algorithms and models were employed for data analysis purposes. After training the machine learning (ML) models, the outcomes of the binary classifiers were grouped. Model selection is YOLO v5, a state-of-the-art object detection model, was chosen for its efficiency and accuracy in detecting objects, including sign language gestures. YOLO v5 utilizes a

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CNN architecture with anchor boxes to detect objects within an image[16][14].

After model selection, to expedite the training process and improve performance, transfer learning was employed. A pre-trained YOLO v5 model, trained on a large-scale dataset (e.g., COCO), was used as a starting point [10]. The pre-trained model's weights were loaded, and fine-tuning was performed on the sign language gesture dataset. Python was chosen as the programming language for this project, and deep learning and ML frameworks, such as TensorFlow, were utilized for implementing the model to support hearing-impaired students.

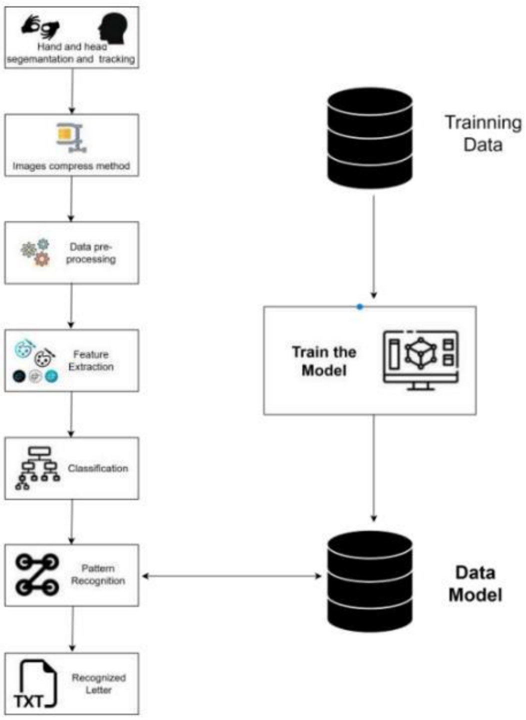

Figure 3: Model training and configuration

Model configuration and Training Process: The YOLO v5 model was configured with appropriate parameters, such as the input image size, number of anchor boxes, and confidence threshold. These parameters were adjusted to suit the characteristics of sign language gestures and the requirements of the dataset. The training process involved feeding the training set through the YOLO v5 network. The model made predictions for each image, and the loss function was computed based on the predicted bounding boxes and ground truth annotations. The gradients were then back propagated through the network to update the model's parameters using an optimization algorithm (e.g., stochastic gradient descent).

Hyperparameter tuning and Evaluation: The hyperparameters of the YOLO v5 model, including learning rate, batch size, and number of epochs, were fine-tuned using the validation set. Multiple training iterations were performed with different combinations of hyperparameters to find the optimal configuration[17][18]. Once training was complete, the trained YOLO v5 model was evaluated using the testing set. The model's performance metrics, such as precision, recall, and mean average precision (MAP)[18], were calculated to assess its accuracy in detecting sign language gestures.

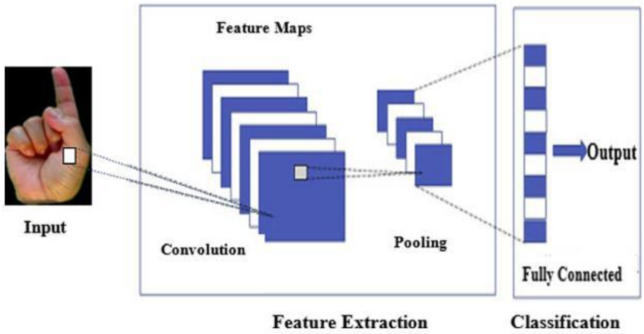

Figure 4: Sample input and output of the image processing process

IV. SYSTEM OVERVIEW

Below five system functions aim to create a comprehensive and interactive learning environment for deaf students in mathematics education. By researching and incorporating sign language for mathematical concepts and basic operations, learners can engage with the content more effectively. The use of cutting-edge computer vision and machine learning techniques enables the evaluation of learners' progress through quizzes, providing personalized feedback. Additionally, the development of highly interactive games, designed using machine learning techniques and incorporating sign language, enhances the learning experience for simple sentence questions. A student profile system allows for tracking progress and evaluating the effectiveness of the curriculum for teaching number patterns. Through testing and evaluation, these integrated system functions strive to promote inclusivity, enhance learning outcomes, and foster a positive educational experience for deaf students in mathematics [6].

A) Teach and evaluate knowledge about numbers and basic mathematical operations in mathematics

Provides deaf students with an interactive learning environment where they can study and evaluate numbers in Sri Lankan Sign Language (SL) through quizzes. Purpose of this, a web application that offers interactive lessons for SL number identification at the primary level was created. Students will have access to lessons via their smartphones and be able to learn independently at their own speed. Students will take quizzes to evaluate their understanding of the numbers taught

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after each class. By displaying the relevant SL number through the camera, students react to quiz questions, and their responses are scored. The app will monitor and display each student's growth. Allow students to track their progress over time and provide feedback on their performance.

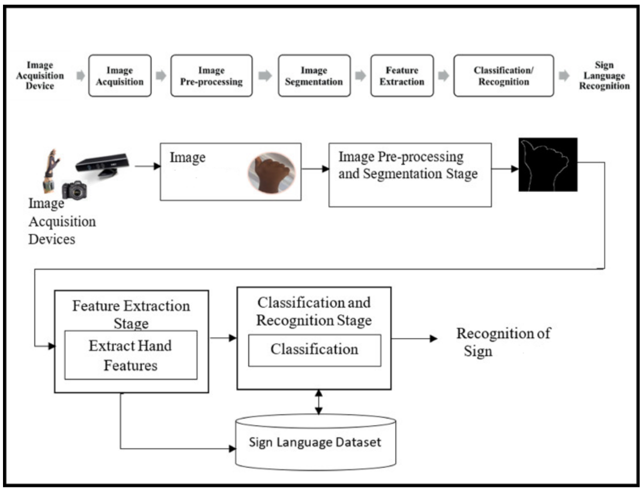

Figure 5: Image Extraction Process

B) Teach basic shapes and construct simple sentence questions and evaluate knowledge through quiz

A number of math lessons including Sinhala simple math sentences, and basic shapes are taught through sign language for hearing-impaired (deaf) students. The unique thing about this is that it can be used for self-study. Students can access lessons designed specifically for them. Students take a quiz at the end of each class to evaluate their awareness of the material provided. They are graded and have the option to respond by showing the correct signal to the camera. A student's growth is shown following lessons. Current students can assess their level of growth and select whether they need to review the lesson. Evaluations are designed to include input in sign language to determine the comprehension of students. The camera pre-processes and segments the pictures it took[14]. Photos captured by the camera are separated and pre-processed to remove the background and capture only the hands. Students receive scores according to the method in which they uploaded the information after the mark is determined using a model that has been trained.

C) Teach number patterns, simple units, measurements, colors and evaluate knowledge

To teach about number patterns, simple units, measurements, and colors, a set of lessons is designed. The creation of lesson plans, activities, evaluations, and other curriculum components follows established methods of instruction and learning objectives. The system will further alter the curriculum by developing learning tools that support and engage students with different types of learning preferences, such as diagrams, animations, graphs, and presentations, among others. visual aids to evaluate students' progress regarding color, simple units, measurements, and number patterns in connection with learning objectives.. To monitor and record the growth of students over time, a system to generate student profiles will be established. A quiz is offered for each lesson to determine whether the student understood it. Quizzes and other tasks are graded to determine the progress of the student. The student profile contains information about the growth of an individual, achievements, and remarks. Parents and teachers of students can access the student profile system to view the progress of their students.

D) Teach number patterns, simple units, measurements, colors and evaluate knowledge

Create interactive lessons to teach elementary school students about basic banknotes and coins. After each lesson, the student is given a quiz to check their understanding of what was taught. They can respond by displaying the correct sign that declares the money on camera and they are evaluated. Each student's progress is evaluated after attending lessons and then displayed. The system monitors each student's progress and provides feedback in the form of a grade displayed on the application. This allows students to monitor their progress and identify areas where additional support may be needed. The system has a database that houses lesson plans, sign language videos, and quiz questions and answers. Additionally, it has analytics tools to track student performance and progress, as well as an image recognition engine to accurately assess sign language responses. Lack of interactive learning tools for deaf students. Resources that combine sign language, visual aids, and interactive components to promote the learning of mathematical concepts may be lacking.

E) Student Profile system

The Student Profile System component of this research involves the design and implementation of an innovative method to record and track students' progress and performance within the learning environment. By collecting data from quizzes and evaluations, this system creates personalized profiles for each student, capturing their strengths, areas for improvement, and overall engagement. The methodology includes the development of data storage techniques, user interfaces for accessing profiles, and integration with the broader learning environment. Through rigorous testing and evaluation, the effectiveness of the Student Profile System in providing insights into individual learning trajectories and enhancing overall educational outcomes will be assessed [5].

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IV. RESULTS AND DISCUSSION

The trained models were tested on the test data to get the corresponding accuracies of classification of collected data from hand signs through a web camera.

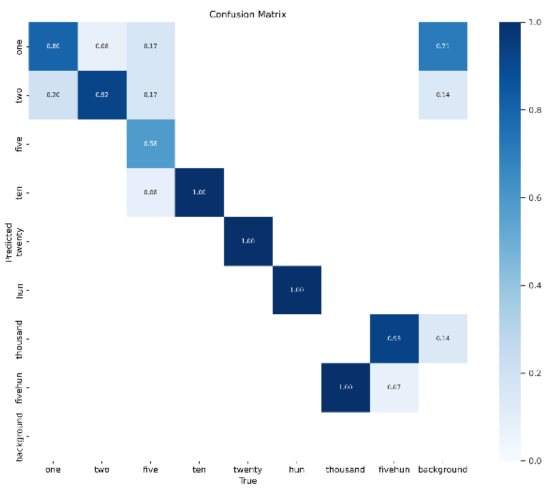

Figure 6: Confusin matrix of the model

A highly accurate confusion matrix provides a detailed representation of the performance of a classification model. It precisely measures the true positive, true negative, false positive, and false negative predictions, enabling a comprehensive evaluation of the model's effectiveness [15][17]. In a previous study, a deep learning model was developed using TensorFlow and Keras, with a training duration of around 35 minutes. This model attained a remarkable accuracy of 97% after 30 epochs, employing a learning rate of 0.01. In contrast, my research extended the training process to approximately 6 hours, while retaining the identical learning rate of 0.01, as part of an effort to enhance model performance [10]. The improved model achieved a higher accuracy of 98% in 100 epochs. Similarly, TensorFlow and Keras were employed for implementation.

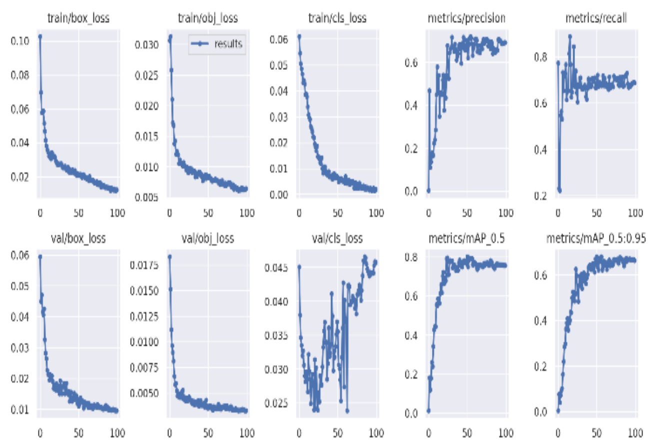

Figure 7: Success – loss rate of the model

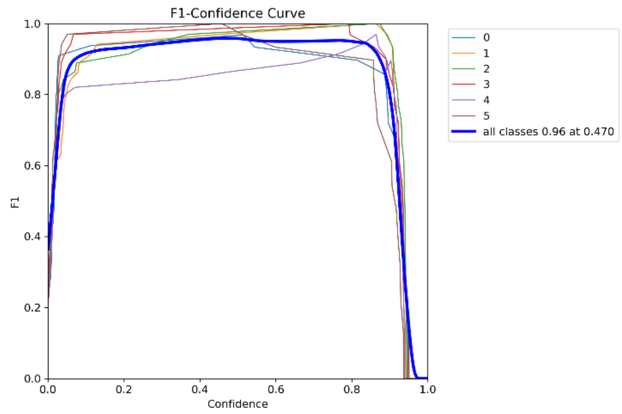

Figure 8: Confidence curve of the model

A highly accurate confidence graph visually represents the level of confidence or certainty associated with the predictions made by a machine learning model [15][14]. Confidence curve is observed around the confidence level of 0.46, where all classes achieve a consistent confidence score of 0.96. This uniform high confidence across various classes underscores the model's ability to make accurate predictions within this range. This finding is particularly significant, as it showcases the model's proficiency in correctly classifying instances across different categories, demonstrating its robustness and reliability. It displays the probability or confidence scores assigned to each predicted class, allowing for a detailed analysis of the model's confidence in its predictions [17]. This graph provides valuable insights into the reliability and precision of the model's predictions, aiding in decision-making and evaluating its performance.

V. CONCLUSION

The system is designed to help deaf children learn mathematics in Sinhala. Currently, there are many systems for a child to learn mathematics, but the systems available for deaf children to learn mathematics are the least. The reason for this is that it is difficult to teach a deaf child a subject like mathematics through sign language. Especially since the main mother tongue of Sri Lankan students is Sinhala, currently learning from developed applications is not practical for Sri Lankan students.

So, we created a web application for a primary student to learn mathematics alone in the Sinhala language where we basically teach numbers and teach basic math karma and teach colors and teach sentence math and teach basic shapes and teach currency notes and coins that we use in Sri Lanka. First, they created a very quality teaching environment for students to learn. It is taught through video and the student listens carefully to the video and then directs a questionnaire to the student. The deaf student has to give the answer by signing to the webcam. Later, a report containing the student's score is

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generated, from which it can be concluded that the student has successfully understood his math knowledge. Here, the sine answer given by the student is detected by the CNN algorithm.

This web application is very important for hearing-impaired students in a country like Sri Lanka because basic math knowledge is required to live in any country. For some time, Sri Lankan hearing-impaired students did not have an accurate and practical mathematics learning environment and our web application can be introduced as a high-quality solution to the problems faced by hearing-impaired students in Sri Lanka in learning mathematics.

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