GESTULEARN: HAND TRACKING AND GESTURE RECOGNITION TECHNOLOGY FOR ASSISTIVE TEACHING IN SPECIAL EDUCATION

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ABSTRACT

Students with disabilities have received inadequate attention in terms of their engagement with technology. Research pertaining to this area is underdeveloped and while generic research often excludes this sector of the student population. Special education gives students with disabilities the opportunity to get quality education in line with their unique needs. As children progress through different stages, guided and comprehensive education becomes a cornerstone for maximizing their potential. Proper education equips them with the tools to navigate the challenges of abstract thinking and cultivates a well-rounded cognitive. Appropriate assistive technology has a direct impact on the well-being of children by supporting their functionality and inclusion into society, thereby increasing the opportunities for education. The project "GestuLearn" is an interactive learning system that utilizes real-time hand detection, tracking, and gesture recognition via computer vision, customized programming, and machine learning algorithms that is designed for assistive teaching to aid students with disabilities particularly the deaf, mute and with learning disabilities.

1. 0 INTRODUCTION

According to United Nations International Children's Emergency Fund (UNICEF, 2022) nearly 240 million people with disabilities are children which is equal to 1 in 10 children worldwide. Focusing on the children that are deaf, mute and with learning disabilities, in the context of special education, students with disabilities who are mute typically face challenges in verbal communication and may not use spoken language. While those students who are deaf experience a significant or complete hearing loss, affecting their ability to perceive auditory information. Lastly, students with learning disabilities refer to cognitive challenges that impact a person's ability to acquire, process, and apply information effectively.

Appropriate assistive technology has a direct impact on the well-being of children by supporting their functionality and inclusion into society, thereby increasing the opportunities for education, employment, and social engagement. It is a key enabler of participation. (Henrietta H. Fore, Executive Director of UNICEF) The existing research on students with disabilities inadequately addresses their engagement with technology, resulting in a lack of attention to their unique needs (Batanero, et. al., 2022). This exclusion and underdevelopment in research studies pose significant barriers that hinder these students' learning experiences. Barriers that students with disabilities face are the challenges in verbal communication, particularly the deaf, mute, and with learning disabilities. Special education teachers encounter the challenge of facilitating effective communication for students with disabilities. Through non-verbal communication such as hand gestures, it offered an alternative means of expression, allowing teachers to communicate and express effectively what they are teaching (Burgstahler, 2022).

The project "GestuLearn" is an interactive learning system that utilizes real-time hand detection, tracking, and gesture recognition with the use of computer vision and machine learning algorithms which is designed for assistive teaching. It is intended to help students with disabilities, especially the deaf, mute, and those with learning disabilities, through forms of non-verbal communication activities such as sign language teaching tools, visual gesture handwriting, visual communication methods, and fine-motor skills training. This study is a way of removing barriers to communication and give students improved educational experience. Lastly, the study aims to design and implement an assistive technology in teaching which aims to address the barriers and unique needs of students that have various disabilities and aid special education teachers on the difficulties in teaching and communicating with the students.

2. 0 REVIEW OF RELATED WORK

2.1 Importance of Technology in Special Education

The observation that students with disabilities have received limited attention in terms of their technology use is a upsetting reminder of the urgent need for inclusivity in research. Little focus has been placed on how students with disabilities utilize technology in their daily lives, despite these educational improvements. This is hardly surprising considering the lack of developed research on children with impairments, while generic research often excludes this sector of the student population. This may be a challenge in terms of ensuring equal opportunities to access and benefit from digital technologies. (Batanero, et. al., 2022)

Bridging the research gap and leveraging assistive technology can positively impact educational outcomes for students with disabilities. A wide variety of technology has been created to diminish or eliminate barriers faced by people with disabilities, especially barriers related to computers and technology. Hardware and software tools–known as assistive technology– can aid in tasks such as reading and writing documents, communicating with others, and searching for information online. As the types of assistive technology expand, and as mainstream technologies become more accessible, students and employees with disabilities are more and more capable of handling a wider range of activities independently. Still, people with disabilities continue to face a variety of barriers to computer use. (Burgstahler, 2022) Ensuring equal access to education for all students, irrespective of their abilities, is pivotal in fostering a more inclusive society. Students with disabilities face a set of barriers that limit their learning and achievement in different activities that take place in the classroom setting. It is essential that these students have access to the same opportunities to participate in society as their peers. (Batanero, et. al., 2022) By breaking down educational barriers, we cover the way for a future where students with disabilities are not only learners but active participants who contribute meaningfully to various aspects of society.

2.2 Interactive Systems for Students with Disabilities

Interactive systems for students with disabilities play a crucial role in promoting inclusive education and providing equal access to learning opportunities. These systems utilize technology to address the unique needs and challenges that students with disabilities may face, enabling them to participate more effectively in educational activities. Those activities include kinetic educational games use movement, where traditional games are more stationary. Some types of kinetic-educational games may be played on a Wii or SMART board, which detects the movement of students. Based on Kosmas, Ioane, and Retails (2018) which studied the effects of game-based learning on students diagnosed with attention deficit hyperactivity disorder (ADHD). Throughout this research, Kosmas, Ioane, and Retails (2018) found children with ADHD who used kinetic-based educational games showed improvement with their academic and self-regulation skills.

Game-based learning is a nontraditional approach which introduces students to game-based learning instead of more traditional paper and pencil activities. Multiple researchers have found game-based learning raised test scores, allowed for hands on social skill lessons, and has helped generate a positive environment for students. (James, 2020) Now, Gesture-based games seem to have potential in dealing with challenges since they require users to move their hands and fingers, can capture their gestures, provide timely feedback, and make motor practice engaging and challenging. Although gesture-based games are promising in the intervention of children with disabilities, relevant research is limited. (Cai et. al., 2018)

2.3 Hand Tracking and Hand Gesture Technology

Hand gestures are a form of nonverbal communication that can be used in several fields such as communication between deaf-mute people, robot control, human–computer interaction (HCI), home automation and medical applications. The camera vision-based sensor is a common, suitable and applicable technique because it provides contactless communication between humans and computers. (Oudah, Al-Naji, & Chahl, 2020)

Hand tracking and gesture recognition has been incorporated with activities for children with disabilities. In the demonstration project of Vukicevic, et. al. (2019), Fruits, the name of the collective VR game suite for developing motor skills in children with ASD included four different games aimed at developing both static and dynamic motor skills. Where the four games were Sorting, Catching, Imitating, and Searching, each addressing the development of different skills. The Sorting game provides an exercise in selective attention, focusing on a given task, visuomotor coordination, concentration, and motor planning. The Catching game addresses head-hand coordination, catching, and balance. The Imitating game facilitates practicing gross motor skills like jumping, squatting, head and arm control, and trunk stability. The Searching game stimulates concentration and creativity. There results showed significant changes in their participants' gross motor skills before and after the experimental group's 5-week game-playing intervention.

Another study that incorporates the technology with games and activities for children with disabilities is the LexiPal by Saputra, Alfarozi, & Nugroho (2018), which implements multisensory approach using Natural User Interface (NUI). NUI is implemented by incorporating several technologies including mixed reality, non-contact human-computer interaction, or motion detection. LexiPal utilizes Microsoft Kinect as a prominent motion sensing device. Kinect enables user to control and to interact naturally with games or other applications without the need to physically use the controller such as mouse, keyboard, and game controller. Lexipal was designed by considering the problems of dyslexic children in learning to read and the best practice to teach them in remediation program setting. Observation in dyslexia therapy and classes were conducted at headquarter of Dyslexia Association of Indonesia in Bandung, Indonesia, to gain basic learning requirements of dyslexic children and practical implementation of multisensory approach by teacher/therapist.

3.0 METHODOLOGY

3.1 Methods of Data Collection

The researcher gathered and analyzed various literature and studies from relevant resources such as various studies and publications, and reliable online sites. To further have an idea on how to proceed with this research. A preliminary and follow-up focused interview were conducted with a Special Education Teacher III and the Educational Program Supervisor SPED from the Tanauan City South Central School SPED Center. With this type of interview, the researchers asked a series of questions about the processes involved in students' learning and the difficulties in teaching the different cases of students with disabilities.

3.2 System Development Flow

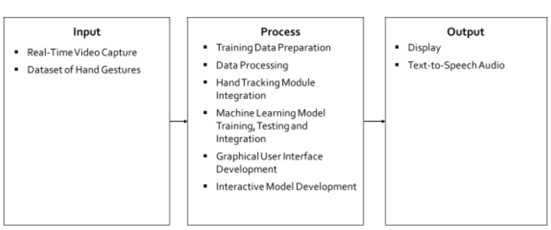

Fig. 1. Conceptual Framework

The system development follows the input-process-output model, The process begins with the input which is the data collection, such as real-time video captured by a camera and a dataset for hand gesture recognition. The system will be developed in a Python virtual environment, where it will use The Mediapipe Hands and CVZone Hand Tracking Module for the system's hand detection and tracking. Then, in the process phase, using the 21 hand landmarks of the hand tracking modules, specific gestures are programmed into the system when these gestures have been detected by the camera, it would output an action or a response in the system. Moreover, data preparation and cleaning is done before the machine learning model training and testing. The system will also use a character detection library and a text-to-speech audio library for certain functions of the system. After these processes, the interactive model is to be developed together with the graphical user interface. Lastly, it would lead to outputting the display and speech audio and sounds for the learning of the students.

3.3 Verification Plan

The research employs a quantitative design involving a pre-test phase for students with disabilities. This initial assessment establishes a baseline performance before the introduction of the experimental treatment which is the use of the assistive learning technology-based system. Then, a post-test is conducted to reassess the students' performance, allowing for a comparison between the post-test and pre-test scores. A paired t-test will be used as the statistical analysis for this research. The verification plan for this study will consist of five phases, which are the validation testing, prototype setup, preliminary evaluation, prototype testing, and feedback evaluation. These phases are the process to achieve the objective of evaluating the performance of the system in terms of speed, reliability, effectivity, and ease-of-use. While the accuracy would be evaluated under different categories based on the different system technologies.

Prototype Setup. The system is set up with a laptop computer, a webcam, an external monitor, speakers and a cooling system.
Validation Testing. Accuracy, speed, and reliability are measured through repetitive tests, evaluating correct and incorrect predictions, timing processes, and assessing the system's performance over time.
Preliminary Evaluation. The study assesses participants based on their existing skills as evaluated by their respective teachers. It establishes a baseline performance.
Prototype Testing. The system is implemented and tested in a real-world scenario, involving teachers

and students to be familiar with the system through provided tutorials. Users interact with the system by standing in front of the camera input hand gesture movements to access the system's functionalities.
Feedback Evaluation. The users will evaluate the system's effectiveness, and ease-of-use guided by the evaluation. Moreover, the respective teachers will again evaluate the performance of the student after using the system.

4.0 RESULTS AND DISCUSSION

4.1 Prototype Setup

Fig. 2. Prototype Setup (Hardware)

The setup is composed of a laptop computer, a webcam, a 27-inch monitor display, a cooling pad, and an external speaker. This setup would allow the teachers to assist the student with disability by having controls using the laptop computer, while the student would face the monitor and be in range with the camera while interacting with the system. Refer to Appendix A for the components.

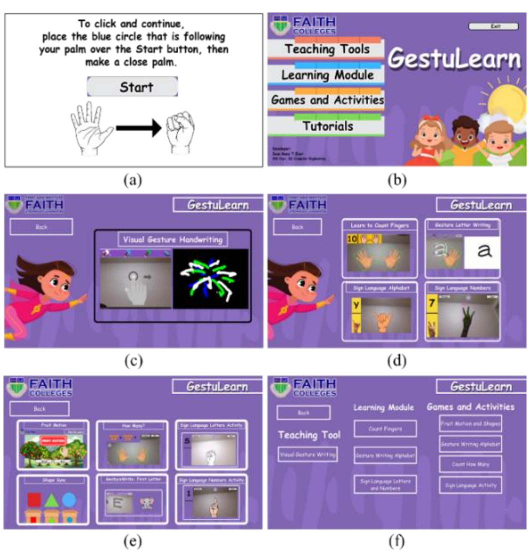

Figure 3. Prototype Setup (Software)

The system application consists of different features such as a preliminary page, the main dashboard, teaching tool, learning modules, games and activities, and tutorials which build the different functions of the system.

Preliminary Page and Main Dashboard. The preliminary page shown in Figure 3(a) is a feature that allows the user to understand how it would be able to interact with the system. Furthermore, after finishing the preliminary page, it will jump to the main dashboard shown in shown in Figure 3(b) which will allow the user to select the different categories that is developed in the system such as the teaching tools, learning module, games and activities and tutorials.

Teaching Tool. The teaching tool that is shown in Figure 3(c) involves Visual Gesture Handwriting. This activity would allow teachers and students to be able to write in the air and display what they have written on the monitor. This allows the user to have a natural user interaction with the technology and provides an interactive and creative way of teaching and learning.

Learning Modules. These learning modules which is shown in Figure 3(d) are composed of interactive learning activities such as Counting Fingers, Gesture Letter Tracing, Sign Language Alphabet, and Sign Language Numbers.

Learn to Count Fingers. This learning module consists of using two hands which would allow the user to count from 0-10 by raising and folding their fingers within the range of the camera. It uses the hand tracking module's hand landmarks where it counts how many of the fingers is up, and how many of the fingers is down.

Gesture Letter Tracing. This feature allows users to trace the small letters in the alphabet with the gestures they create, and check using a character detection library of python if they accurately traced the letter.

Sign Language Alphabet. In this feature, it uses a trained Keras model that allows the system to predict if the gesture made is right. The user will just show in the camera the correct hand gesture for the specific letter and allow the system to predict if the gesture they made is correct.

Sign Language Numbers. This feature allows the user to learn sign language numbers from 0-10 where uses the hand landmarks of the hand tracking module that is programmed by the developer to detect when the made gesture by the user for the sign language numbers is correct.

Games and Activities. This category which is shown in Figure 3(e) are composed of 6 activities which includes Fruit Motion, Shape Sync, Count How Many, GestureWrite: First Letter, Sign

Language Alphabet Activity, and Sign Language Numbers Activity.

Fruit Motion and Shape Sync. These are sorting activities which would allow users to sort the fruits or the shapes using the hand tracking feature of the system. Users would drag their hand within the range of the camera to move the shape on the screen and put them in their proper categories.

Count How Many. This is an activity where the user would need to use addition and count how many objects are there in the shown picture.

GestureWrite: First Letter. This activity would show a picture and users should input the proper first letter of the picture shown. It is an activity for students to know what word they interpret based on the picture they see.

Sign Language Alphabet and Numbers Activity. This game and activity feature is a way to determine what the user knows about the sign language alphabet and numbers. It shows their knowledge of the Sign Language Alphabet.

4.2 Validation Testing

Through validation testing it would assess and evaluate the different features of the system. It would be evaluated by accuracy, speed, and reliability.

4.2.1 Accuracy Testing

The system features are categorized into 4 different types, of which the technology used in each feature.

Table 1. Categories of System Features based on its Technology.

System Feature	*Technology*
Learning Module: Learn to Count Fingers *Games and Activities: Count How Many*	*Hand Tracking Module, Customized Program for Count Fingers Up*
Learning Module: Gesture Letter Tracing *Games and Activities: GestureWrite: First Letter*	*EasyOCR Character Detection Library with Customized Program*
Learning Module: Sign Language Alphabet *Games and Activities: Sign Language Alphabet Activity*	*Keras Machine Learning Model for Sign Language Alphabet*
Learning Module: Sign Language Numbers *Games and Activities: Sign Language Numbers Activity*	*Hand Tracking Module, Customized Program for Sign Language Numbers*

Table 2. Hand Tracking Module, Customized Program for Count Fingers Up Accuracy Summary

Counting Numbers	Test Samples	No. of Correct Gestures	Percentage (%)
Total	110	110	100%

A total of 10 tests which tried to mimic counting from 0-10 using their fingers, and tested if the system would be able to detect if the number of the fingers up corresponds to the correct or predicted number of fingers up. Based on the table, 110 out of 110 gestures (100%) got identified and passed correctly through the system. Refer to Appendix B.

Table 3. EasyOCR Character Detection Library with Customized Program Accuracy Summary

	Test Samples	Number of Correct Prediction	Percentage
Overall Total	260	222	85.38%

A total of 10 samples for each letter have been drawn using the gestures of the hand and been tested using the EasyOCR character detection library. Based on the table, 222 out of 260 gestures (85.38%) got identified and passed correctly through the system. Refer to Appendix C.

Table 4. Keras Machine Learning Model for Sign Language Alphabet Accuracy Summary

	Test Samples	Number of Correct Prediction	Percentage
Overall Total	270	260	96.29%

A total of 10 test users tried to mimic the sign language alphabet, and tested if the system would be able to detect if the gesture made corresponded to the correct sign language alphabet. Based on the table, 260 out of 270 gestures (96.3%) got identified and passed correctly through the system. Refer to Appendix D for the tally.

Table 5. Hand Tracking Module, Customized for Sign Language Numbers Accuracy Testing

Sign Language Numbers	Test Users	No. of Correct Gestures	Percentage (%)
Total	110	110	100%

Again, a total of 10 test users tried to mimic the sign language numbers, and tested if the system would be able to detect if the gesture made corresponded to the correct sign language number. Based on the table, 110 out of 110 gestures (100%) got identified and passed correctly through the system. Refer to Appendix E.

4.2.2 Evaluation of the Speed of the System

To test the speed of the system lines of code are added in between the main code which uses the cv2.tickCount function to get the time at certain parts of the program, through computation the elapsed time would be shown.

Refer to Appendix F for the result of the latency for each feature. It shows the results of the speed of the system and the frames it renders per second depending on the feature that is in use at the time. The median score shows that the system operates at 9.91 frames per second (FPS).

4.2.3 Evaluation of Reliability of the System

Table 6. Reliability of the System Testing

Test 1		Test 2		Test 3	
Operating Time	No. of Failures	Operating Time	No. of Failures	Operating Time	No. of Failures
30 minutes	0	30 minutes	0	30 minutes	0
1 hour	0	1 hour	0	1 hour	0
1 hour and 30 minutes	0	1 hour and 30 minutes	0	1 hour and 30 minutes	0

The reliability of the system is tested 3 times by using the system for different time periods. These time periods are based on the duration of one class of special education students. Based on the table there have been no failures out of the three time periods and the three tests made.

4.3 Preliminary Evaluation, Prototype Testing, and Feedback Evaluation

Figure 4. Photos of Implementation

To evaluate the effectivity and the ease-of-use of the system, this project is implemented at the SPED Center in Tanauan City South Central School. For the effectivity, a total of 12 students from the target participants which are from the primary level 1 and 2 students with disabilities and primary deaf and mute students have been pre-assessed and post evaluated by their respective teachers based on an evaluation sheet approved by the mentor and the special education teachers of the SPED Center at the Tanauan City South Central School. The teacher evaluated the students based on a 1-4 scale where 4 being the highest and 1 being the lowest.

Refer to Appendix G, I and J. Comparing the results of the pre-test and post-test using paired t-test, where the null hypothesis shows that there is no significant difference in the performance of the students before and after using the interactive learning system. While the alternative hypothesis shows that there is significant difference in the performance of the students before and after using the interactive learning system.

Computing for the p-value or t is equal to 0.000000000017 or 1.70159E-11. With a significance level (α) = 0.05, the p-value is less than the significance level, which means rejecting the null hypothesis. Therefore, there is significant difference in the performance of the students before and after using the interactive learning system.

Ease-of-Use. A total of 6 Special Education Teachers has evaluated the ease-of use of the system based on the interaction of their students in using the learning application. The average scores shown on the table above ranges from 3.83-4. The overall average score is 3.96. (Refer to Appendix H, and K)

5.0 CONCLUSION

The researcher was able to develop 11 system features that are aligned with the forms of non-verbal communication activities such as sign language teaching tools, visual gesture handwriting, visual communication methods, and fine-motor skills training. The system's performance for the accuracy which was categorized based on the technology used resulted in the following: Hand Tracking Module, Customized Program for Count Fingers Up showed a 100% accuracy; EasyOCR Character Detection Library with Customized Program showed 85.38% accuracy; Keras Machine Learning Model for Sign Language Alphabet showed 96.29% accuracy; Hand

Tracking Module, Customized Program for Sign Language Numbers showed 100% accuracy. The system's overall performance in terms of speed which was through validation testing averaged to 9.91 frames per second. Through testing the system's reliability for 3 trials with 3 different span of time the system would be running it had showed that there were no errors during the event. For its effectivity, from a p-value that showed 0.000000000017 or 1.70159E-11 which is less than the significance level, which is 0.05, this means it rejects the null hypothesis. Moreover, the positive mean difference and the small p-value indicate that the post-evaluation are significantly higher than the pre-test. Therefore, there is a positive significant difference in the performance of the students before and after using the interactive learning system. Noting that this is only for the sample of students who tested the system. For the ease-of use, where a total of 6 special education teachers evaluated the system, the overall average score is 3.96, which is a rating of 99%.

6.0 RECOMMENDATIONS

As stated in the conclusion there have been a positive significant difference in the performance of the students before and after using the interactive learning system only for the sample of students who interacted with the system. The researcher would recommend expanding the study's scope can further reach to a more general conclusion. Furthermore, exploring more about the learning modules used for special education and devise a way on how the other modules can be integrated with the Hand Tracking and Gesture Recognition Technology.

7.0 ACKNOWLEDGMENT

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8.0 REFERENCES

1. Batanero J., et. al. (2022). Assistive technology for the inclusion of students with disabilities: a systematic review. Retrieved from https://link.springer.com/article/10.1007/s11423-022-10127-7
2. Burgstahler S. (2022). Working Together: People with Disabilities and Computer Technology. Retrieved from https://www.washington.edu/doit/working-together-people-disabilities-and-computer-technology
3. Cai S. (2018). A case study of gesture-based games in enhancing the fine motor skills and recognition of children with autism. Retrieved from https://doi.org/10.1080/10494820.2018.1437048
4. James M. (2020) The Impact of Game-Based Learning in a Special Education Classroom. Retrieved from https://nwcommons.nwciowa.edu/cgi/viewcontent.cgi?article=1240&context=education_masters
5. Kosmas, P., Ioane, A., & Retails, S. (2018). Moving Bodies to Moving Minds: A Study of the Use of Motion-Based Games in Special Education. Tec Trends: Linking Research & Practice to Improve Learning, 62(6), 594–601.
6. Oudah M., Al-Naji A., & Chahl J. (2020). Hand Gesture Recognition Based on Computer Vision: A Review of Techniques Retrieved from https://doi.org/10.3390/jimaging6080073
7. Saputra M. Alfarozi S. & Nugroho K. (2018). LexiPal: Kinect-based application for dyslexia using multisensory approach and natural user interface. Retrieved from https://doi.org/10.1504/IJCAT.2018.10014728
8. Ugalde L. (2021). Impact of Interactive Learning Environments on Learning and Cognitive Development of Children With Special Educational Needs: A Literature Review. https://doi.org/10.3389/fpsyg.2021.674033
9. Vukicevic S. (2019). A Demonstration Project for the Utility of Kinect-Based Educational Games to Benefit Motor Skills of Children with ASD Retrieved from https://doi.org/10.1177/0031512519867521

9.0 ABOUT THE AUTHORS

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10.0 APPENDIX

Appendix A – System Components

Hardware Components	Software Components
Logitech C922 Pro Webcam	GUI Interactive System
Huawei Matebook D15	Text-to-Speech Audio Output
Zeus Multi-Media Soundbar Speaker	Mediapipe and CVZone Hand Tracking Module
Nvision 27-inch Monitor Display	easyOCR Character Detection Library
	Keras Machine Learning Model

Appendix B – Hand Tracking Module, Customized Program for Count Fingers Up Accuracy Testing

Counting Numbers	Test Users	No. of Correct Gestures	Percentage (%)
0	10	10	100
1	10	10	100
2	10	10	100
3	10	10	100
4	10	10	100
5	10	10	100
6	10	10	100
7	10	10	100
8	10	10	100
9	10	10	100
10	10	10	100
Overall Total	110	110	100

Appendix C – EasyOCR Character Detection Library with Customized Program Accuracy Testing

Gesture Written Letters	Test Samples	Number of Correct Predictions	Gesture Written Letters	Test Samples	Number of Correct Predictions
a	10	8	n	10	7
b	10	10	o	10	10
c	10	10	p	10	9
d	10	10	q	10	3
e	10	8	r	10	9
f	10	9	s	10	10
g	10	10	t	10	10
h	10	10	u	10	9
i	10	0	v	10	4
j	10	8	w	10	10
k	10	10	x	10	10
l	10	8	y	10	10
m	10	10	z	10	10

Appendix D – Keras Machine Learning Model for Sign Language Alphabet Accuracy Testing

Sign Language Letters	Test Users	Number of Correct Prediction	Sign Language Letters	Test Users	Number of Correct Prediction
A	10	10	N	10	10
B	10	10	O	10	10
C	10	10	P	10	10
D	10	10	Q	10	10
E	10	10	R	10	10
F	10	10	S	10	8
G	10	10	T	10	8
H	10	10	U	10	8
I	10	10	V	10	8
J	10	10	W	10	8
K	10	10	X	10	10
L	10	10	Y	10	10
M	10	10	Z	10	10
			Open Palm	10	10

Appendix E – Hand Tracking Module, Customized for Sign Language Numbers Accuracy Testing

Sign Language Numbers	Test Users	No. of Correct Gestures	Percentage (%)
0	10	10	100
1	10	10	100
2	10	10	100
3	10	10	100
4	10	10	100
5	10	10	100
6	10	10	100
7	10	10	100
8	10	10	100
9	10	10	100
10	10	10	100
Overall Total	110	110	100

Appendix F - Results of Speed Evaluation of the System

Parts of the System	Frames per second (FPS)
Preliminary page	9.884194
Main Dashboard	9.931309
Transition pages	9.96796
Visual Gesture Handwriting	15.04475
Learn to Count Fingers	9.9153
Gesture Letter Tracing	15.24298
Sign Language Letters	6.183373
Sign Language Numbers	9.911376
Fruit Motion	9.954644
Shape Sync	9.905611
Count How Many?	9.911219
GestureWrite: First Letter	15.09203
Sign Language Activity Letters	5.544754
Sign Language Activity Numbers	9.90456

Appendix G – Effectivity Pre-test and Post-test Average Evaluation Result

	Pre-test Average	Post-test Average
User 1	1.4	4
User 2	1.6	4
User 3	1.4	4
User 4	1.4	4
User 5	1.9	4
User 6	1.8	4
User 7	1.7	4
User 8	1.3	4
User 9	1.4	4
User 10	1.8	4
User 11	2	4
User 12	1.8	4

Appendix H – Ease-of-Use Average Evaluation Result per Criteria

	Average Score
Criteria 1	4
Criteria 2	4
Criteria 3	3.83
Criteria 4	4
Criteria 5	3.83
Criteria 6	4
Criteria 7	4
Criteria 8	4
Criteria 9	4
Criteria 10	4

Appendix I – Pre-test Evaluation Criteria

Pre-test
The student is familiar with using hand gestures for interaction
The student has a very good understanding of the concept of using hand gestures for communication and interaction
Before incorporating hand tracking and gesture recognition technology, students with diverse abilities faced challenges in accessing learning materials and participating in activities.
Gauge the student's attitude towards integrating

technology into their learning experience, specifically using hand gestures.
Rate the student have previous experience with technology (e.g., using computers, tablets, etc.):
How comfortable is the student with learning and using new technologies?
Evaluate the student's digital literacy skills, including familiarity with using technology interfaces and devices.
Assess the student's fine motor skills
Assess the student's ability to mimic hand gestures
Determine the extent to which the student is aware of the purpose of the hand gesture learning system.

Appendix J – Post-test Evaluation Criteria

Post Test
Assess how well the student adapted to the system's requirements (e.g., hand positioning, movement).
Evaluate the student's learning in performing the required hand gestures.
Evaluate the accessibility of learning materials and activities for students with the use of hand tracking and gesture recognition technology.
The technology contributed to increased motivation and self-confidence in students with special needs, encouraging them to actively participate in learning activities.
The system improved the student's proficiency in using hand gestures.
The technology made the student be confident in using hand gestures for interaction after using the system?
Evaluate the individualized interactions of the student with the technology
Assess the student's fine motor skills
Assess the student's ability to mimic hand gestures
Assess the student's collaboration and engagement during activities using hand gestures.

Appendix K – Ease-of-use Evaluation Criteria

Accessing content or activities offline was convenient and well-supported.
The implementation provides clear instructions on how to interact with the learning materials and activities.
The application's interface and controls are intuitive, requiring minimal effort to learn.
The menus, buttons, and links were clearly labeled and guided you through the application.
The application's interface is designed in a way that makes it easy to find and access different features.
The layout and design of the application are visually appealing and user-friendly.
Learning materials (videos, audios, and activities) were presented in a visually appealing and organized manner.
Interactive elements were intuitive and enhanced user engagement with the content.
The application exhibited stability and minimal technical glitches during your usage.
Overall, I find the learning application to be user-friendly and easy to navigate.