ASHESI UNIVERSITY

signWithMe: Intelligent Learning System for Inclusive Learning of the Ghanaian Sign Language

APPLIED PROJECT

Capstone Project submitted to the Computer Science Department, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Management Information Systems.

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APPLIED PROJECT

B.Sc. Management Information System

Petra Mensah Abosi

2022

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

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Candidate's Name:

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Date:

……

I hereby declare that the preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature:

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Supervisor's Name:

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Date:

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Acknowledgement

With heartfelt gratitude, I would like to thank my supervisor, Dr David Ebo Adjepon-Yamoah, for guiding and supporting me in doing this wonderful project on the topic *signWithMe: Intelligent Learning System for Inclusive Learning of the Ghanaian Sign Language.*

Also, I acknowledge the entire Computer Science and Information System faculty for the knowledge imparted to me throughout my academic years at Ashesi University.

Finally, I would like to thank my parents, siblings and friends who encouraged and supported me in completing this project within the limited time frame.

Abstract

There are many Deaf people in the world, and in Ghana, there are many Deaf persons. However, there is a huge communication gap between the Deaf and hearing in the Ghanaian society, as there is inadequate teaching and learning of the Ghanaian Sign Language. In this project, the signWithMe application system seeks to address this problem by providing a Sign Language application system that consists of a Sign Language dictionary, a translator, an e-resource, an e-forum and an e-payment system. It would educate people about the Deaf community to ensure diversity and inclusion in our society. This system will use web features, a payment and a chatbot Application Programming Interface (API).

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Chapter 1: Introduction

1.1 Background

According to the World Health Organisation [1], over 1 billion people live with some form of disability. Out of that populace, about 430 million people, including children, have complications with their hearing ability [2]. The World Health Organisation defines hearing loss as someone who cannot hear within the hearing thresholds of 20dB or better in both ears. Some of the causes of hearing loss and Deafness include genetic factors, childhood diseases and infections, excessive noise, and old age [2]. Hearing loss conditions result in one becoming hearing-impaired, thus, Deaf or hard-of-hearing.

Although the world knows about hearing impairment, there is little attention and impact on ensuring a safe space for the hearing impaired. The following paragraphs explain some of the issues in the Deaf community. For instance, Alexander Graham Bell [3], the telephone inventor, sought to purify the human race by eradicating Deafness. He did this by forbidding Deaf people from communicating through Sign Language.

In addition, there are about 8.9 million [4] Deaf children in Sub Saharan Africa, and Africans see them as a bad omen. Hence, they are discriminated against and left in isolation as they are deemed a burden in their respective families. Most African societies stigmatise the Deaf and refer to them as "deaf and dumb" [5].

Moreso, the census report from the Ghana Statistical Service showed that as of 2010 [6] in Ghana, with a population of 24,658,823 people, 737,743 were hearing impaired. Ghana's attitude towards Deafness stems from the same African behaviour. A young boy shared his

narrative in one article [7], "at home, I generally feel lonely," says Obed Dekyi, a student. "There is no one to communicate with me. Besides, there are no other Deaf children to reach out to for a conversation or a game."

1.2 Problem Definition

Interestingly, more than 90% of Deaf children are born to hearing parents [8]. However, not all parents know how to communicate with their Deaf children. Nevertheless, these parents need to communicate with their children as it could affect their development [9]. Members of society must support families with Deaf children by learning how to communicate with the Deaf children to promote harmony, inclusion, and diversity in society, as there is a huge communication gap between sign language and oral language [10].

Moreover, many Deaf people are illiterate or semi-illiterate. The illiteracy rates among the Deaf in most countries are above 75% [11], and a few get into higher education. Usually, they get little or no education leaving them to depend on their families constantly. It stagnates their growth as individuals, and they suffer a lot from low self-esteem. As stated in Henner et al.'s report [12], Deaf children who learn sign language during the childhood stage or school-going period have higher analogical reasoning skills than those who acquired sign language at an adult stage. Hence, there is a need to educate both the Deaf and hearing on sign language to ensure smooth communication and hence, harness the growth of the Deaf community.

1.3 Research Aim and Objectives

Indeed, there are several Sign Language applications in the world. However, there are few Sign language applications in Africa, especially in Ghana. As a result, this research aims to provide educational software that will help teach and learn Sign Language and bridge the communication gap between the hearing and the Deaf. This would be achieved by developing

a web application system with a sign language dictionary, a translator, an e-resource, an e-forum and an e-payment system.

- Objective 1: Development of a Sign Language Dictionary

  The application would be developed and consist of videos on the primary sign language. Thus, the alphabet, numbers, and days of the week are a few to mention.

- Objective 2: Development of a Sign Language Translator

  There would be a translator that will be developed to convert text to sign language. Thus, text-to-sign_language.

- Objective 3: Development of a Sign Language E-payment System

  Also, there will be an e-payment system to enable users of the application to purchase documents for their learning.

- Objective 4: Development of a Sign Language E-Forum

  This allows users to interact and share information about the Deaf and Sign Language. There would be a chatbot to allow users to interact with the administrators for support on the use of the application system.

1.4 Sustainable Development Goals

This research seeks to achieve Sustainable Development Goals 10, 4 and 8 [13]. They are Reduced Inequality, Quality Education, Decent Work and Economic Growth, respectively. The research outcome of this project is a web application that will enable both the hearing and the hearing impaired to communicate with one another. This will help reduce social isolation, loneliness and stigma of the Deaf in society. Instead, there will be harmony since both the hearing and the Deaf in the Ghanaian society can understand themselves.

Besides, the school-going age children will enjoy an innovative method of interacting with their colleagues who are Deaf. It will allow students to learn a language and acquire a new skill. Finally, with the hearing being able to communicate with the Deaf, it will enhance the opportunity for the Deaf to secure jobs in various organisations and institutions across the country. Hence, it would eradicate Deaf people from becoming a burden in several homes and leverage financial growth in such homes.

The diagram below shows the pictorial representation of the above Sustainable Development Goals.

Figure 1: Sustainable Development Goals 4, 8 and 10 [13]

1.5 Summary

There has been a minimal focus on developing a Sign Language application system in Africa, especially in Ghana. This gap will be addressed in this research such that Ghanaian citizens will have the opportunity to access resources about the Deaf and have a forum to learn and practice sign language. The next few chapters explain the methodology, design, implementation and testing of the Intelligent Learning System for Inclusive Learning of the Ghanaian Sign Language.

Chapter 2: Literature Review

The literature review and related works around this problem area are briefly discussed below. Some researchers explained that Deaf people fail to express their feelings and views to the hearing due to the communication barrier [14]. Besides, literature [15] stated that the communication challenges the Deaf encounter affects their learning capabilities and social growth and prevent them from actualising their potential. These researchers stated that modern technology could be used to find solutions to the learning difficulties experienced by the Deaf.

2.1 Deep Learning and Computer Vision

Furthermore, out of the five peer-reviewed papers from IEEE, three researchers [14, 15, 16] used deep learning and computer vision in developing sign language systems. For instance, Utalk [14], Let's Talk [15], and SiLearn [16] were built using Convolutional Neural Networks (CNN). Utalk is a sign language converter that was trained for the Sinhala language. It uses videos, extracts the frame segments from the video, and finally uses CNN to develop a static sign classifier. CNN consists of three main parts; Conv, Pooling and Dense layers. Conv layers consist of filters and feature maps. The Pooling layer reduces the feature obtained in the previous Conv layer. The Dense layer is the standard feed-forward network layer. The dataset was tested and trained via Keras and Tensorflow using a Graphics Processing Unit.

Moreover, researchers in some of the reviewed papers included Support Vector Machine [18, 19] in their implementation. An instance is a mobile application for South African Sign Language Recognition. Michael et al. [18] implemented a mobile platform as it is easy to develop applications. Although, it could be expensive and lack processing power. Their research aim was to focus on recognising the fingerspelling of the manual alphabet and manual

numeric digits. They performed this project using three different classification models. Thus, the log-sigmoid neural network, Elliot neural network and the SVM. The SVM models complex, real-world problems by separating data into two categories while maximising the distance from the separating hyperplane to the nearest instance. The SVM managed to match and outperform the neural networks. However, there is a limitation to how fast a sign can be made. Hence, SVMs were found to be appropriate for sign language recognition and were selected for implementation in the mobile application.

2.2 Web Applications

Other researchers from the reviewed papers [15] used OCR and Web 2.0 features that supported several sign languages. OCR makes use of optical character recognition. The process involves converting the scanned image into a binary image and then analysing connected components to extract character outlines. Below is Table 1, illustrating the relationship between the various methods implemented by each researcher.

Table 1: Comparison Criteria of Literature Review [14, 15, 16, 18, 19]

Number	**Comparison Criteria**	**Utalk**	**Let's talk**	**SiLearn**	**American Sign Language Recognition**	**A mobile system for South African Sign Language Recognition.**
1	Technologies for implementation	Computer vision and machine learning techniques, Static/ Dynamic classifier, OpenCV, CNN	Google cloud speech API, Text to speech, SVM, Camera API, Open CV	Computer Assisted Language Learning, OCR, AI-based techniques like object detection, TensorFlow	Computer vision and deep learning, American Sign Language Dataset, CNN, LSTM, RNN	SVM, Java-based machine learning library, Encog,

2	Performance Details	Utalk achieves high precision and recall values (over 0.90) for all the static signs that it was evaluated for. Further, Table V shows that Utalk can also achieve higher precision and recall values for dynamic signs. These results indicate that the proposed Utalk system can be successfully used for both static and dynamic sign identification.	The Speech to Text functionality operates in the background and can accurately transcribe calls. When tested, 93% of the words were recognised, and conversations were fully captured, whether for calls or during conversations. To respond to interactions, the Text to Speech feature provided users with the ability to voice themselves	Students find using SiLearn with vocabulary learning book very helpful in learning. The availability of mobile phones and picture books make the learning of new words are easy and exciting.	Retraining the final layer of the network in Figure 4 took about 36 hours running on a GeForce GTX 920 GPU. After completing the training steps, the model reported an incredibly high 99% accuracy on the training set.	Three different classification models were optimised, tested and compared. The log-sigmoid neural network had the lowest accuracy of 94% and lacked robustness to noisy inputs. This can be improved through more advanced training techniques. The symmetric Elliott neural network had a higher accuracy of 96%. However, this symmetric activation function did not outperform the asymmetric activation function in training time and took about 40% longer. The SVM had the highest classification accuracy of 99%.

3	Platform of deployment	Mobile application	Android mobile application	Mobile application, Web features	A computing device that can run the vision-based application	Mobile application android and Bluetooth glove
4	Process	Results from sign classifiers are fed into the language model to generate tet based on input. CNN is used for developing the static classifier.	The Text to Speech component uses the Google Speech API to convert written text from the user to speech. Moreover, it allows for adjusting the pitch and speed of the speech. Additionally, it provides a regular keyboard and a Sign Language keyboard, which is handy for	SiLearn includes signs corresponding to 950 words, and the object detection module can detect 15 classes. These 15 classes are objects that can be shown in a classroom setting.	The gesture segments identified and processed by the CNN are classified by the LSTM [7] into one of the gesture classes using sequence data. Since the input segments have to be a fixed size, we trimmed the length of all the frame sequences. We use an LSTM because of its efficiency with longer sequences of data.	An SVM with a radial basis function kernel was used to determine C and B's SVM parameters. A grid search approach finds the lowest values for C and B, producing the highest classification accuracy.

			impaired persons who do not understand normal. The Camera API allows the use of the phone's camera to enable the recognition of the Sign Language through image processing which the OpenCV library performs. SVM compares what the person is signing to the dataset and displays it to the user.		We train the LSTM on the outputs from the CNN Softmax layer and the Pool layer and compare the results. After experimenting with a more profound and broader RNN, we decided that this network architecture gave the best results in accuracy	
5	Limitations	The collection of large	The translation of a	For the first time user, it	Loss of accuracy due to	The SVM has a weakness in its

		datasets is costly. However, to train a deep learning model, there is a need for a large dataset.	complete gesture into text is envisaged. Improving the speech recognition to differentiate between different speakers, thereby notifying this on the scrolling text of the Speech to Text functionality.	needs some training to make it work correctly. Detection accuracy can be improved by feeding the model used for training with more training images. The inception model which we have used achieved 21.2 per cent, top-1 and 5.6 per cent top-5 the error rate for evaluation on the ILSVR 2012 classification. The detection accuracy exhibited by the Inception model is the best among its class.	facial features and different skin tones.	classification time.

2.3 Literature Review Impact on the project

Based on the insight obtained from the research work, this research will consider using a web application system, even though most peer-reviewed researchers implemented the system on a mobile application. The Web application would be implemented to make it convenient and accessible from any portable computing device. Some technologies like HTML, CSS, JavaScript, Ajax, MySQL, PHP and frameworks like Bootstrap will be used in developing the web application system.

Chapter 3: System Requirement and Design

This chapter explains the system requirement documentation that informed the design and testing of the application. This chapter identifies functional and non-functional requirements, user requirements, architectural diagrams, and system constraints.

3.1 Requirement Specification

The methodology used in building this application is the Agile methodology [20]. The agile methodology refers to the continuous interaction with stakeholders from the beginning to the end of the research. The agile method emphasises being people-oriented and communication-centred. This ensures that enough information is obtained in building the Sign Language application. In this project, stakeholders such as the Deaf community, teachers and school authorities constantly gave feedback that influenced some changes in the implementation and usability of the Sign Language application system. For instance, the HandTalk API, which contains signed words from only two countries, thus the United States of America and Brazil would have been used for the Sign Language translation. However, Mr Alexander Bankole, a tutor in the IT department of the Office of Persons with Special Needs at the University of Ghana, shared that the Sign Language application should be built to suit the Ghanaian context.

The design of this application includes both system requirements and user requirements. These requirements were identified based on the need the system is addressing and, most importantly, the feedback obtained from users. User feedback was obtained through interviews and discussions with the primary stakeholders. Thus, the Deaf students and hearing students,

teachers, parents and school administrators. This user feedback informed how the Sign Language Application's system should be implemented. Finally, the Literature Review also informed the requirements for developing the application system.

3.1.1 System Requirements

The system requirements consider the technical features of the sign language system. It serves as the technological aspect of the system, and it ensures that the user's requirements are addressed in the system. After interacting with relevant stakeholders through interviews (see Appendix B), the functional requirement of the system was finetuned. This is to make the system efficient and user-friendly for users. The set of functional and non-functional requirements is provided below.

3.1.1.1 Functional Requirement

These are the functions and features that the application system must provide for users. The functional requirements consist of the following:

- FR01: The Sign Language dictionary must provide users with words and their signs.
- FR02: The Sign Language Translator must provide users with how to sign words.
- FR03: The Sign Language E-Forum must allow users to share their thoughts on the platform.
- FR04: The Sign Language Resources must provide users with data about the Deaf.

- FR05: The e-payment system must enable users to purchase resources about the Deaf.

The web application must have an efficient backend architecture that interacts with the database and updates the frontend of the application system. In Figures 2-5, the use case diagram illustrates the frontend of the sign language application system.

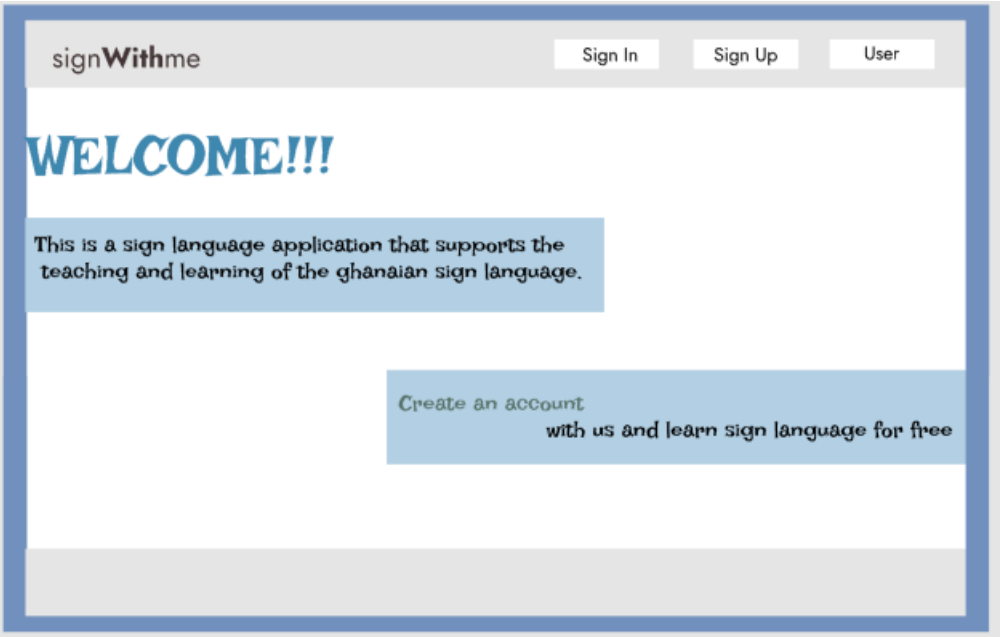

Figure 2: WireFrame diagram of the First Home Page

Figure 3: WireFrame diagram of the Sign-Up Page

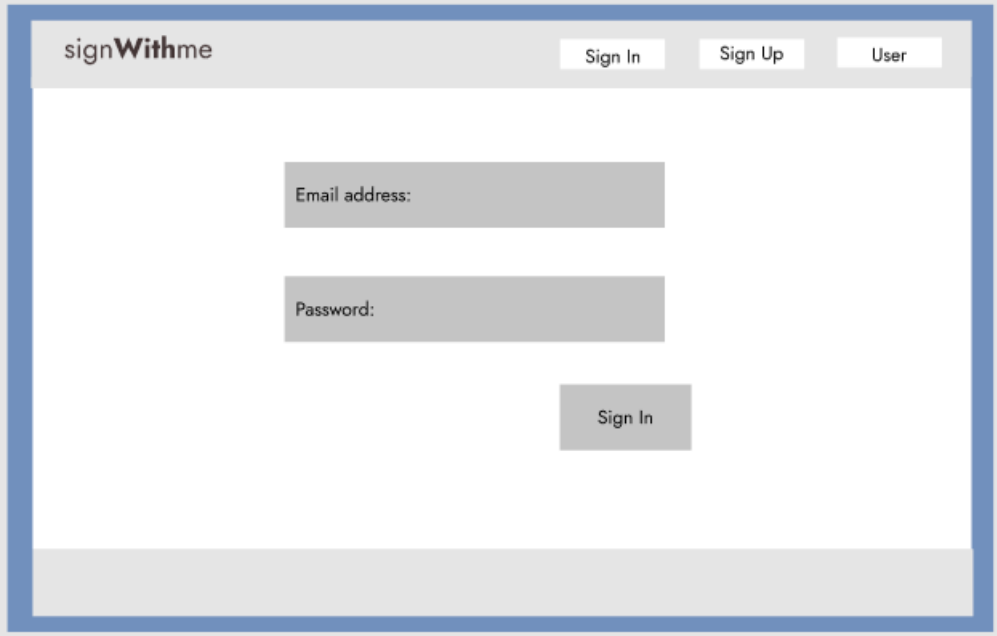

Figure 4: WireFrame diagram of the Sign-In Page

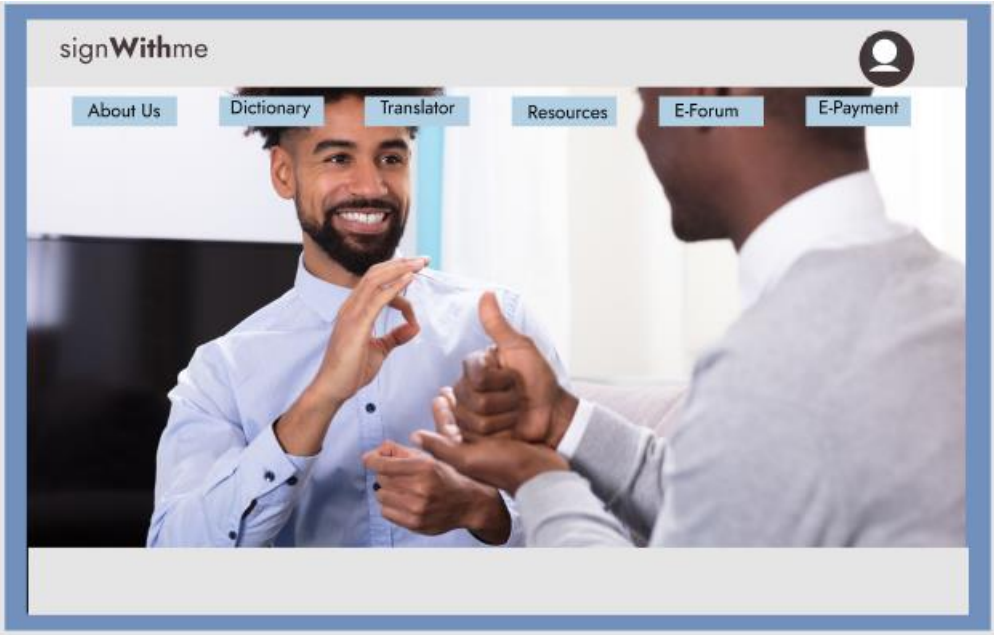

Figure 5: WireFrame diagram of the Second Home Page

3.1.1.2 Non-Functional Requirement

The non-functional requirements are the application system's quality attributes that ensure the usability and effectiveness of the system. The non-functional requirements include:

- NFR01: Require log in credentials to use the system.
- NFR02: Ensure user-friendliness by using Human-Computer Interaction Strategies.
- NFR03: Ensure the availability of the system to users.

Below is the sequence and object diagram, which gives a graphical representation of the system and its usage.

The sequence diagram in Figure 6 shows how the user can utilise the system. First, on the first home page, the user logs in and gains the opportunity to utilise all the functionalities of the system. The user lands on the second home page and can navigate the about page, the

dictionary, the translator, the e-resource, the e-forum and the e-payment system functionalities. After which, the user can log out of the system.

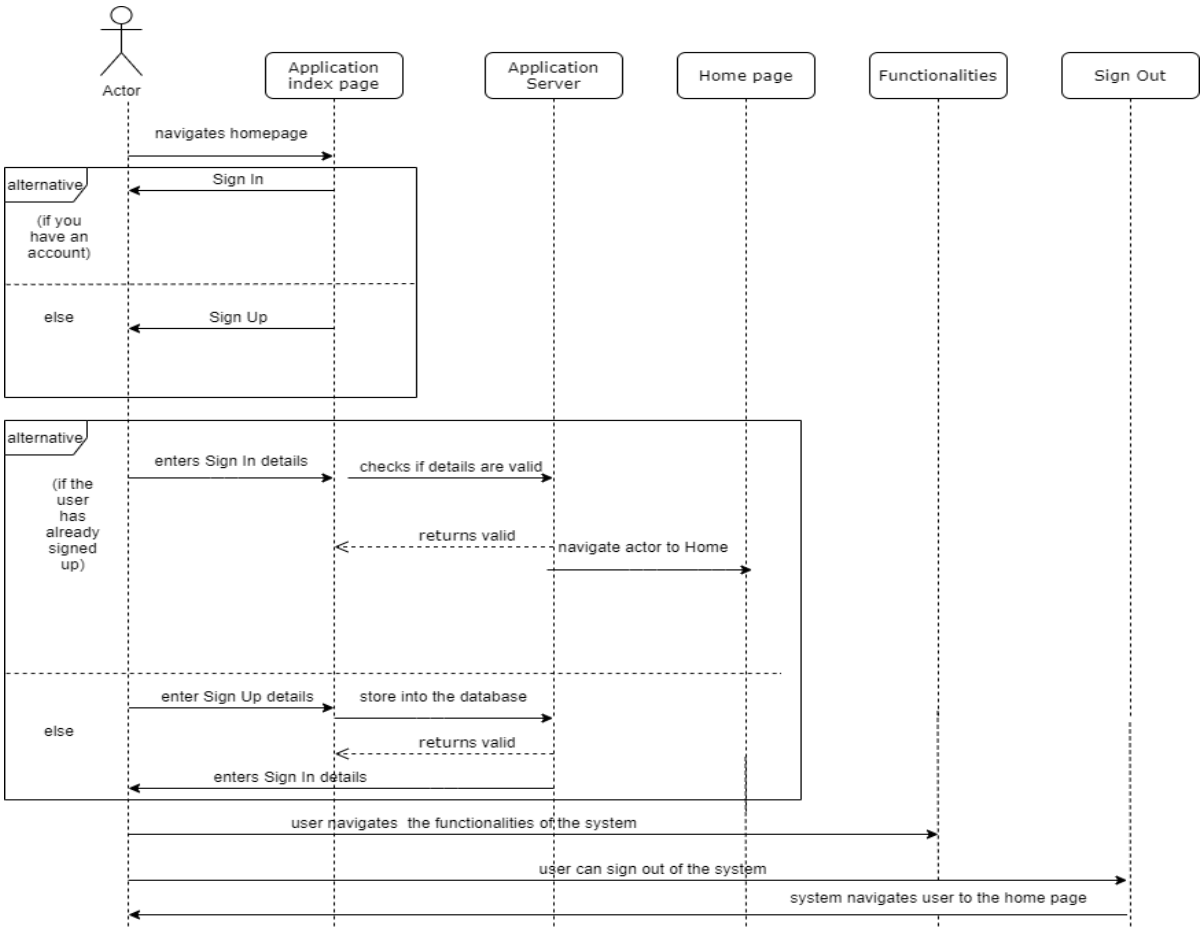

Figure 6: Sequence Diagram

The object diagram in Figure 7 shows the relationship between the objects (user, order and shopping details) in the signWithMe system. It illustrates the connection between the various objects. These objects contain the classes, methods and data types.

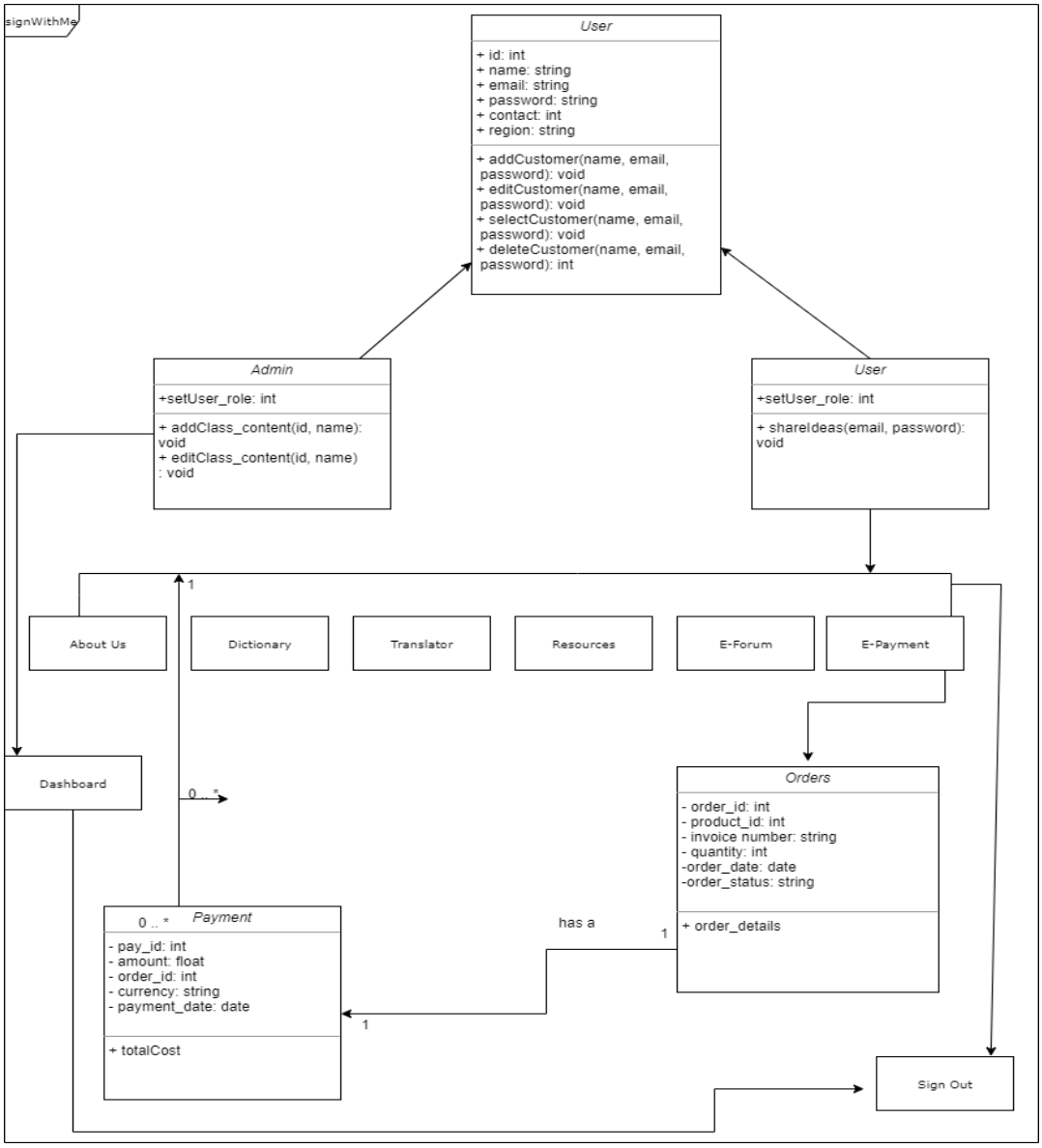

Figure 7: Object diagram

3.1.2 User Requirements

In this project, a qualitative research method was used to acquire data from stakeholders. Thus, interviews were conducted with the teachers and school authorities in the disability department at the University of Ghana, Deaf people at the Nsawam Road Church of Christ and the Demonstration School for the Deaf. During these interviews, Alexander Bankole, who is

blind and a coordinator for Assistive Technology at the Disability Department, shared with the research team the importance of technology and how it can be used to support the disabled. He shared that we should be able to build applications that suit the Ghanaian Deaf community other than trying to adjust the systems meant for the use of a group of Deaf people in another country, say the United States of America.

Most of the teachers shared that students are in dire need; however, resources are inadequate. As a result, students manage to perform well in their majors at the university. Another teacher explained that few Deaf people could rise high up the academic ladder. Many Deaf people end their education at the primary level, and a few of them can secure their education at the tertiary level. Even with that, they do not get the resources and assistance needed to help them ace their education.

Moreover, the Deaf participants during the interview at the church premises shared some challenges they faced communicating with the hearing. An older woman said that sometimes when she picks the public transport, the driver fails to alight her at the specified destination. An old lady explained that the doctor could not treat her as expected when she went to the hospital because of the communication gap. Finally, most of them shared how unhappy they are discriminated against and the disunity between themselves and the hearing in society.

Additionally, the research team's interactions with the teachers and students at the Demonstration School for the Deaf showed that Deaf students are visual learners who can grasp concepts through images, diagrams and videos. This is because they learn or gain knowledge by seeing or visualising. Hence, a visual description helps them in their learning. The Deaf students also shared that they communicate through sign language and chat platforms like WhatsApp. These communication strategies are efficient as they convey their ideas to their

fellow Deaf and the hearing. Refer to Table 2 for a summary or classification of the interview conducted.

Table 2: Classification of the Interview Conducted in the Various Institutions

Participants	**The University of Ghana- Office of Students With Special Needs**	**Mampong School for the Deaf**	**Nsawam Road Church of Christ**
Teachers	Application systems should be built to suit the needs of the Ghanaian Deaf society.	Students use visual displays to learn and grasp content very well.	-
Deaf Students/ Members	-	Students use an online platform like WhatsApp to communicate with people	There is a communication gap between the hearing and Deaf
School Authorities	Students need adequate teaching and learning resources.	-	-

3.2 Scope and Constraints of the System

This defines the system's boundaries as the system must provide a specific set of features that would enhance teaching and learning on the sign language application. The signWithMe application system would have an interactive frontend that provides a sign language dictionary, a translator, an e-resource, an e-forum and an e-payment system. This would enable users to access sign language materials to assist them in the learning process. This sign language application is for both the Deaf and the hearing. The system is specifically being developed to bridge the communication barrier between the Deaf and hearing in Ghanaian society and support Deaf students in learning and using sign language.

Chapter 4: Design and Implementation

Based on both the system and user requirements identified in Chapter 3, the signWithMe web application system has been designed with HTML, CSS, Javascript and Bootstrap to ensure user-friendliness and the practical functionalities of the website. The system has been designed with clear and bold writing, warm colours, and features that ensure the application system's interactivity.

4.1 Data Collection

There was a collection of data as the goal of the signWithMe web application system is to provide Ghanaian Sign Language. As a result, a quality camera was used to capture over one thousand Ghanaian signed words. These videos were edited to suit the implementation of the application system.

4.2 System Design Architecture

The signWithMe system is built as a web system with an efficient backend architecture that interacts with the database and updates the frontend of the system. Figure 8 shows a flowchart diagram that explains how the whole application system operates from start to finish.

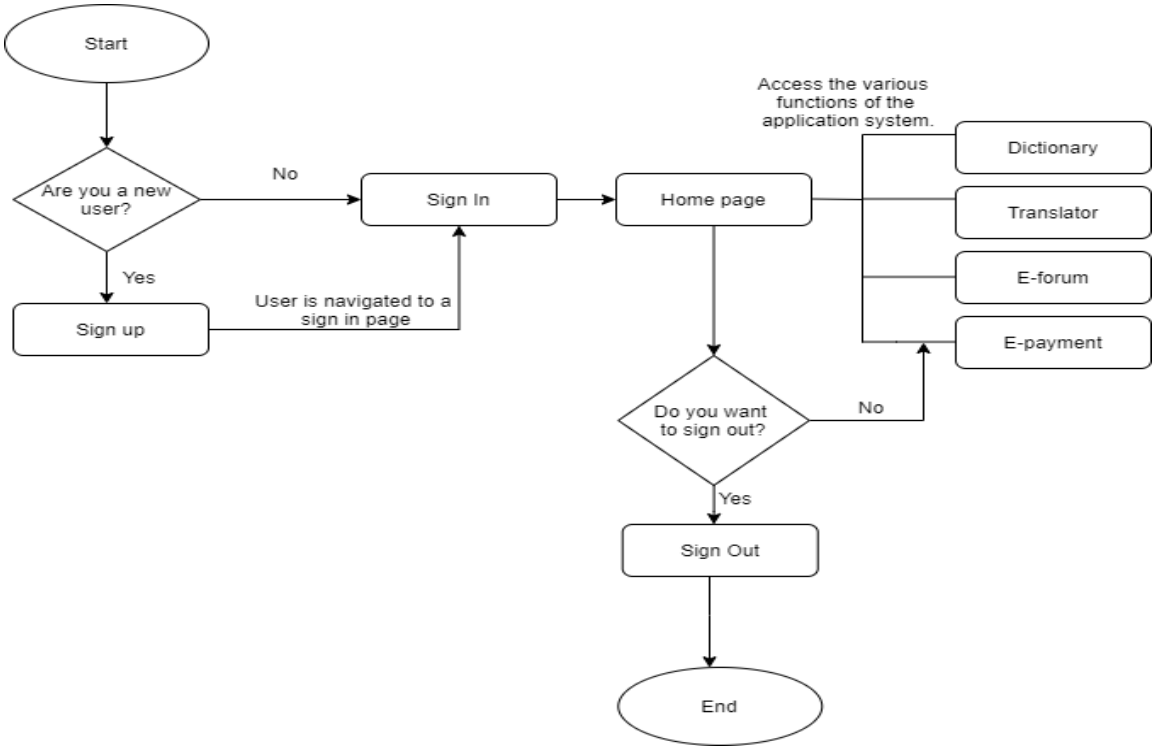

Figure 8: Flow Chart Diagram

4.2.1 Web application architecture using the MVC pattern

From Figure 9, the model view controller (MVC) approach will be used in implementing the sign language system. The system will be structured into three logical components, Model, View and Controller. The model manages the system data and all the SQL queries. It connects directly with the database to provide data. The view defines and manages the display of data to the user. The controller manages user interactions and connects with the model and view to ensure user interactivity with the system. For instance, when users query the signWithMe system for videos on the alphabet, the controller connects with the model—the model also connects with the videos' database. The database has the videos in the alphabet. Then, the view displays the video on the alphabet for the user to learn and interact with the system.

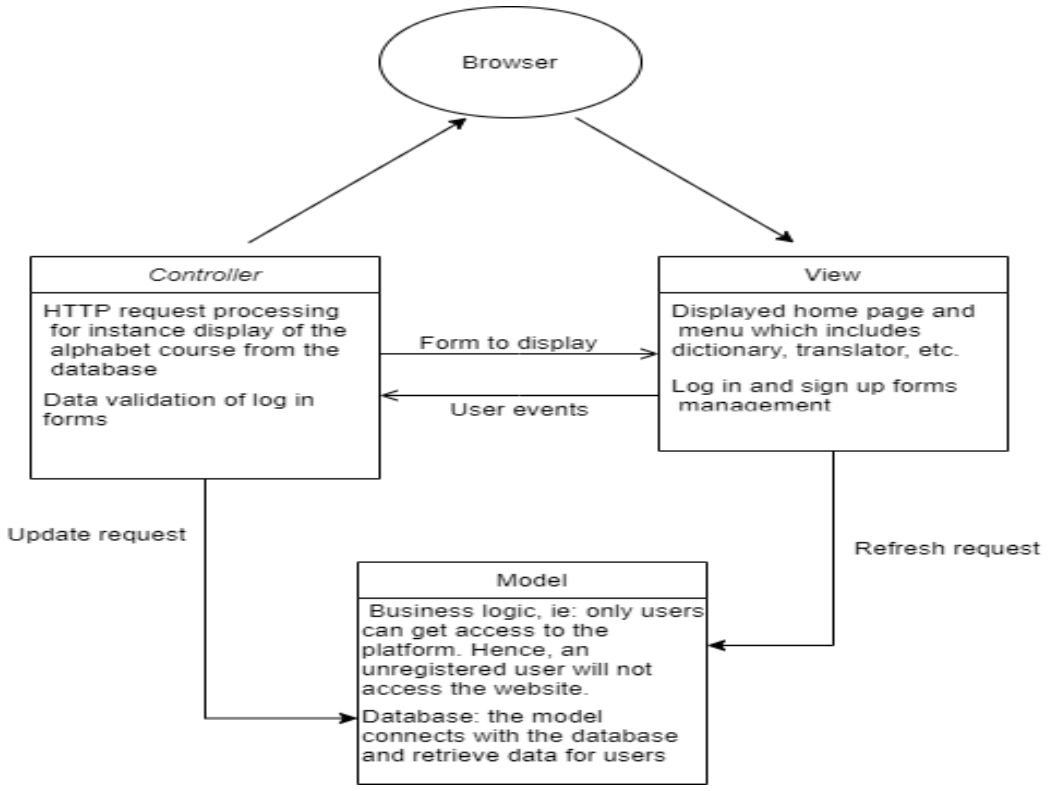

Figure 9: Model View Controller (MVC) Diagram

4.2.2 Layered architectural diagram of a web application

In Figure 10, the signWithMe application has a home page that constitutes the website's background and has a login/sign up functionality that enables users to access the main pages of the application system. A successful log in ushers the user to the landing page of the web application system that has six functions on the Menu bar of the system, namely – an About us page, an SL dictionary, an SL translator, an SL e-forum and an SL e-resource.

The About Us page has information about the use and functionalities of the application system. It has information concerning the purpose of the application system. It was built using HTML and CSS, which vividly displays words and images to users.

The SL dictionary page is a functionality that provides users with signed words to enable them to learn the sign language and practice by solving quiz questions on the topic studied. It was built using HTML and CSS, which displays the videos of signed words with their explanation to users.

The SL translator page is a functionality that provides users with signed phrases and basic sentences used in their everyday life to enable them to learn and practice sign language. It was built using HTML and CSS. Here, users have to input the phrase or words they want to learn its signs. The system retrieves the sign from the database and displays it in a pop-up video to the user.

The SL forum page is a functionality that allows users to interact with one another by sharing their thoughts on the platform. This was built using the Create, Read, Update and Delete (CRUD) functionality that allows users to add, edit and delete information they share on the platform.

The SL e-resources page is a functionality that provides users with resources such as books and learning materials about the Deaf, which they can purchase using the SL e-payment system of the signWithMe web application system. The SL e-resources functionality of the application system was built using HTML and CSS, which displays the learning materials to users and explains the book's content. The "Buy Now" button connects users to Paystack using the Paystack API. This allows users to make payments through Paystack, which is connected to the database to store records of the payment made by users.

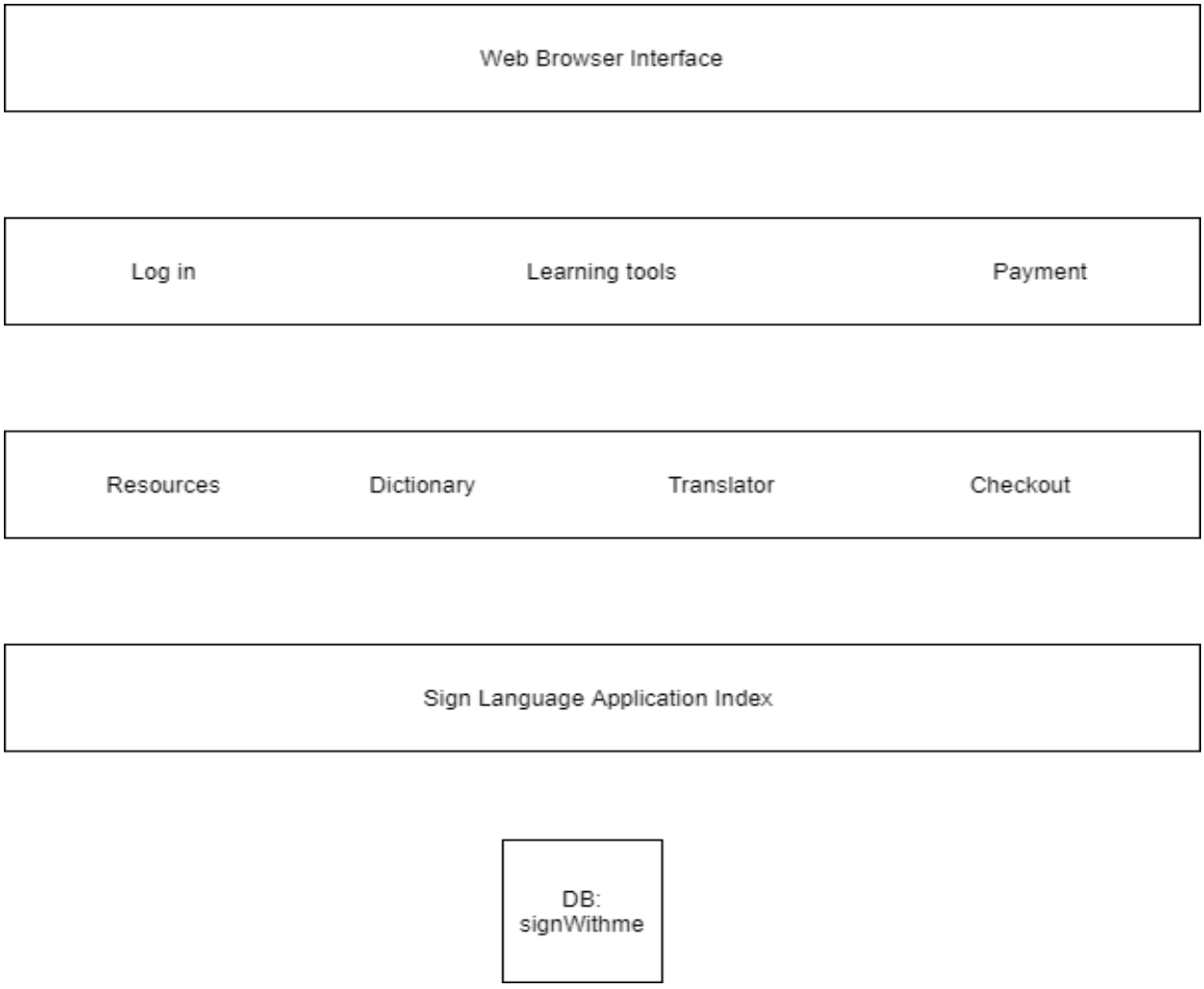

Figure 10: Layered Architectural Diagram

4.2.3 Client-server architecture of a web application

The signWithMe application system was built using the three-tier architecture, as seen in Figure 11. The system is centred on the three-tier architecture system comprising the frontend, backend, and database. The frontend comprises HTML, CSS, JavaScript, and Bootstrap. It displays and collects user information to be processed by the application system. The backend is implemented using PHP. It processes the information obtained from the front end and

performs the business logic required for the successful operation of the system application. It enables us to perform the CRUD operations, thus adding, deleting, and updating data in the database. Finally, the database stores and manages the application system's data. Here, MySQL is used with phpMyAdmin of the Apache server.

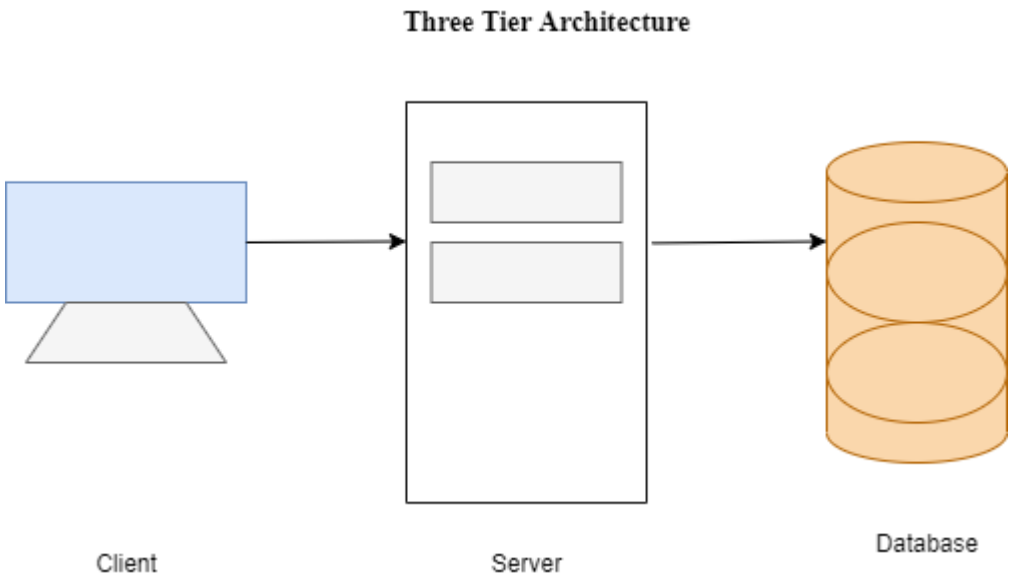

Figure 11: Client-server Architectural Diagram

4.2.4 Database schema

The database has been designed to contain the entities and attributes of the data. The schema diagram below in Figure 12 shows the relationships between tables in the database and their data types.

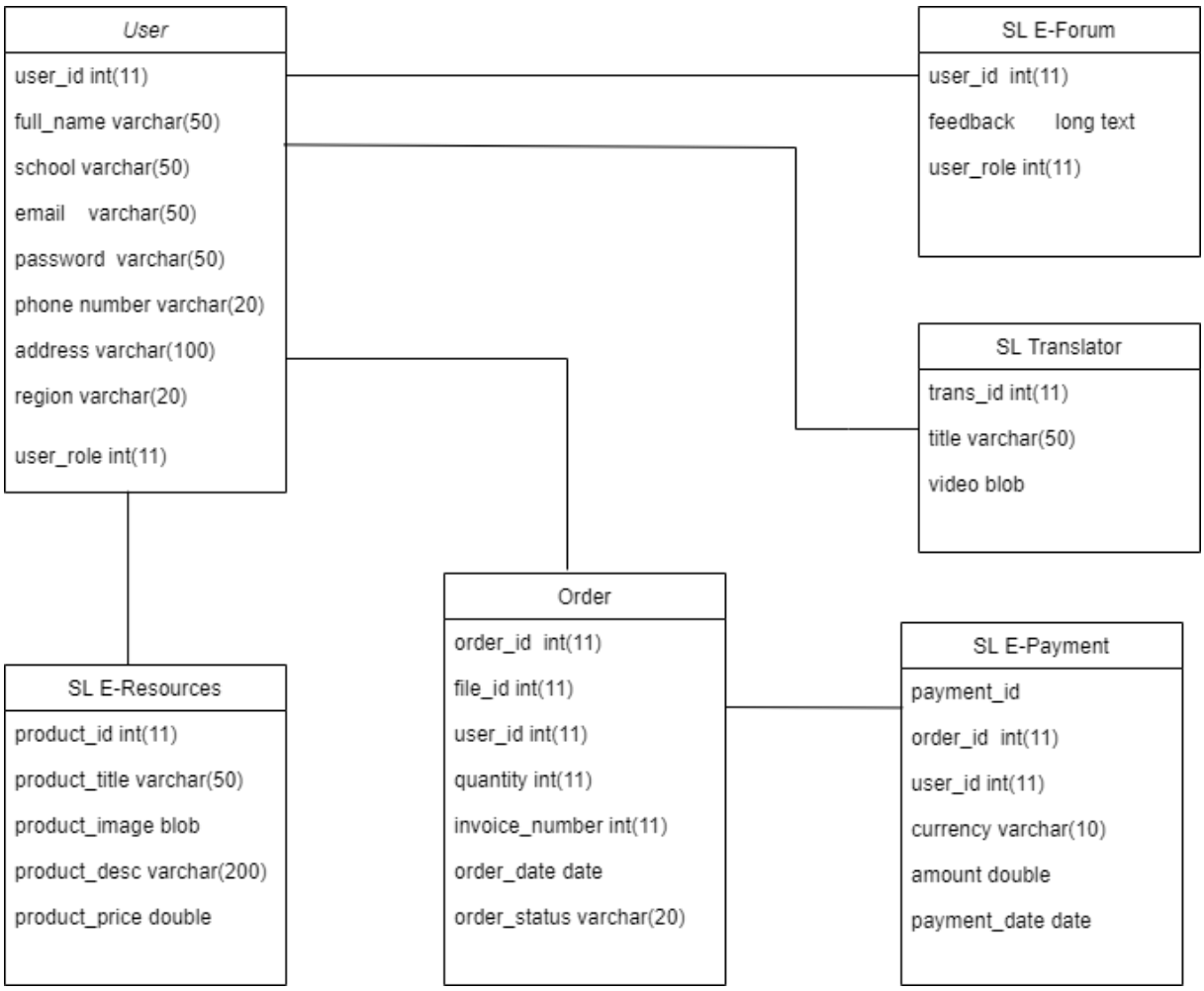

Figure 12: Database Schema

Chapter 5: Testing and Results

In this chapter, two tests were implemented: the unit testing of all relevant methods and functions of the system and the user testing, which was conducted in the Mampong School for the Deaf. From the requirements identified in Section 3.1.1, the signWithMe application system has these functionalities and features that meet the above requirement in Chapter 3. Thus, the application system has a sign language dictionary, translator, e-forum, e-resources and e-payment subsystems. The application system also meets the non-functional requirements. Thus,

- The login/sign up system ensures security by ensuring users login to access the functionalities and features of the application system. The system verifies the user's email address before he/ she can access the application's content.
- The Graphic User Interface (GUI) of the application system has been designed to ensure user-friendliness and interactivity. The navigation of the site is manageable and comprehensible.
- The database and the hosting site have been secured such that the application system would always be available for users.

The following diagrams below are snapshots of the completed signWithMe application system.

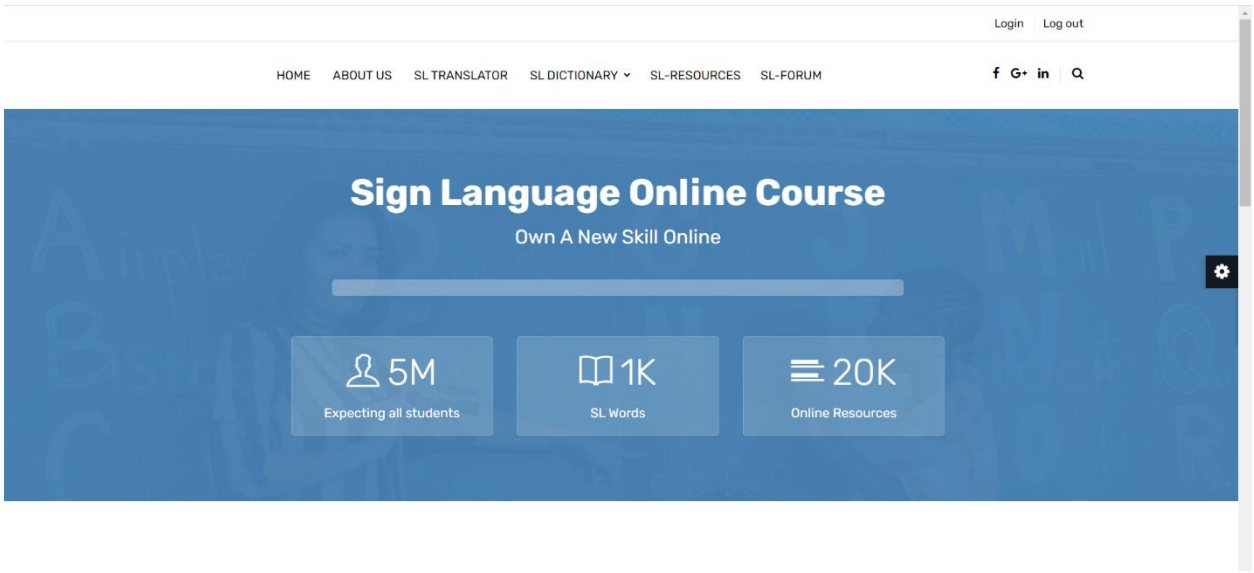

Figure 13: A snap of the Second Home Page

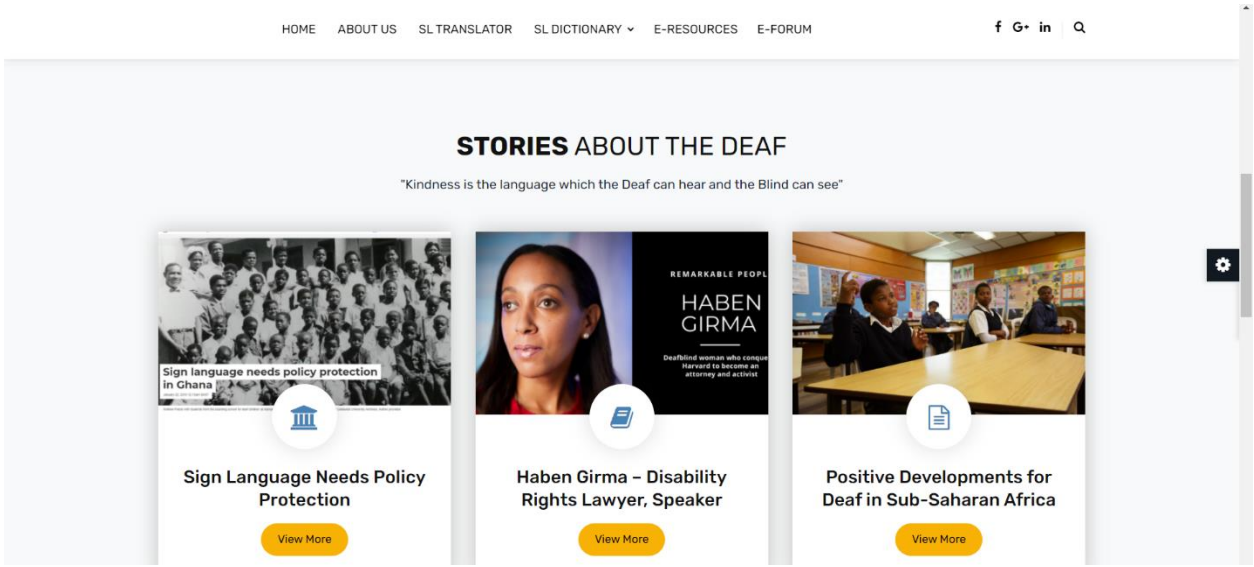

Figure 14: A snapshot of the About Us Page

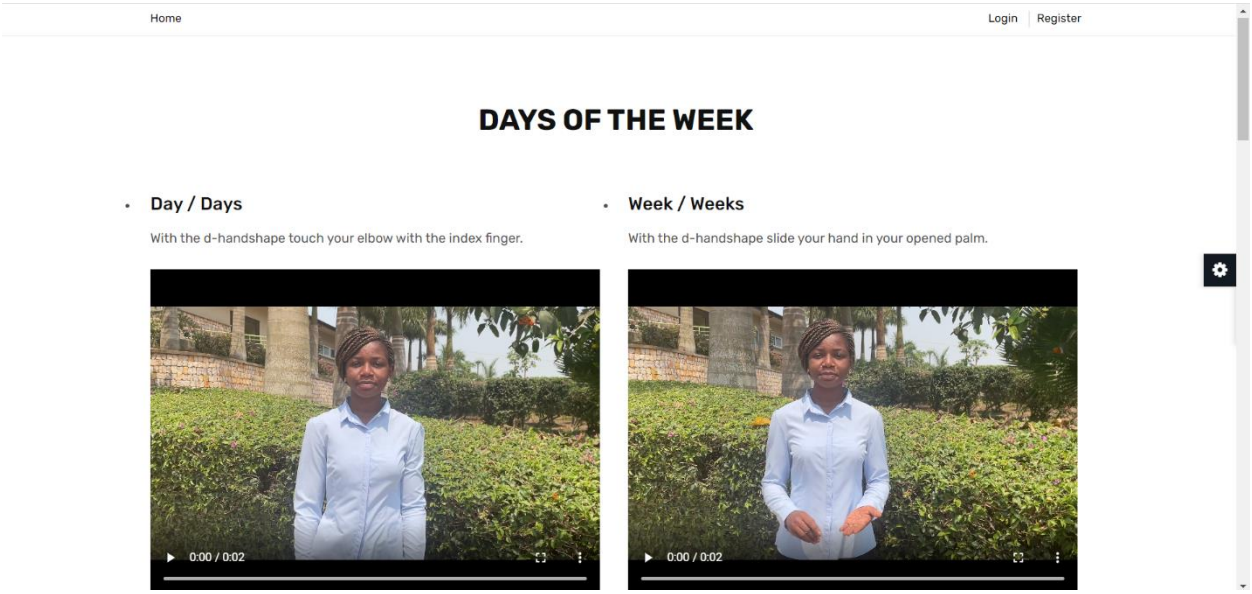

Figure 15: A snapshot of the SL Dictionary

Figure 16: A snapshot of the SL E-Resources

5.1 Unit Testing

The application system was tested using the PHPUnit test since the application's backend was built using PHP. This unit testing is software testing that determines if there are issues in the independent modules of the system and helps determine the efficiency of the written codes. For instance, in Figures 17, 18, 19 and 20, PHP unit testing was performed on the sign language translator, e-resource, e-forum and log in subsystems of the signWithMe application system. The snapshots below show the result of the tests.

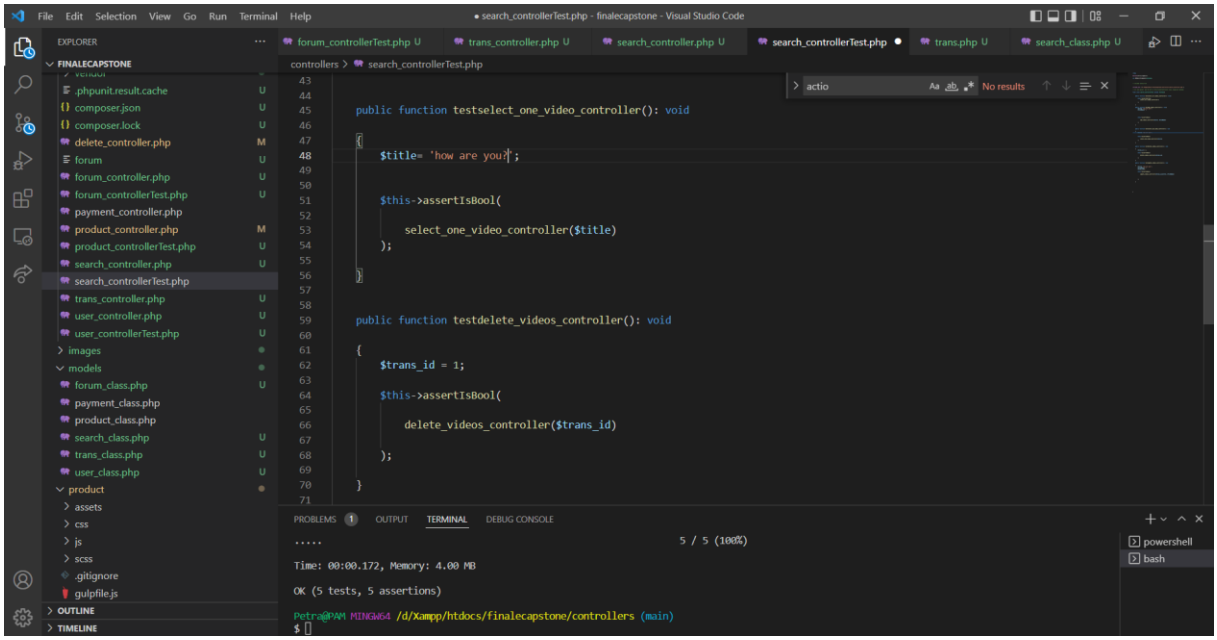

Figure 17: PHP Unit Testing for the sign language translator

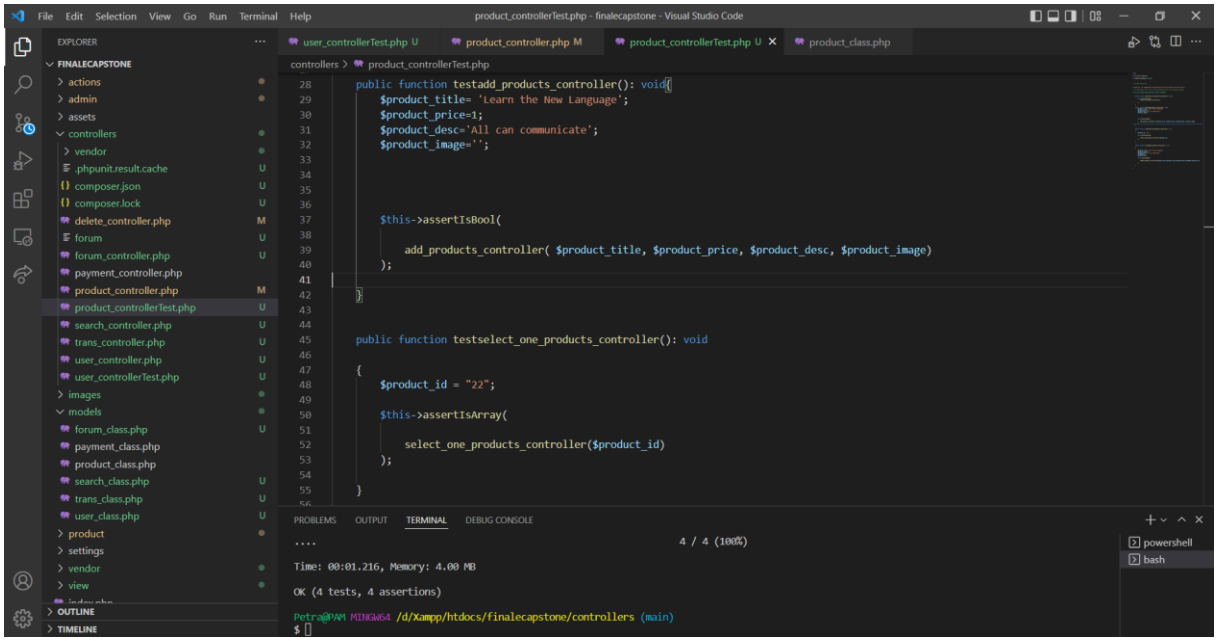

Figure 18: PHP Unit Testing for e-resources

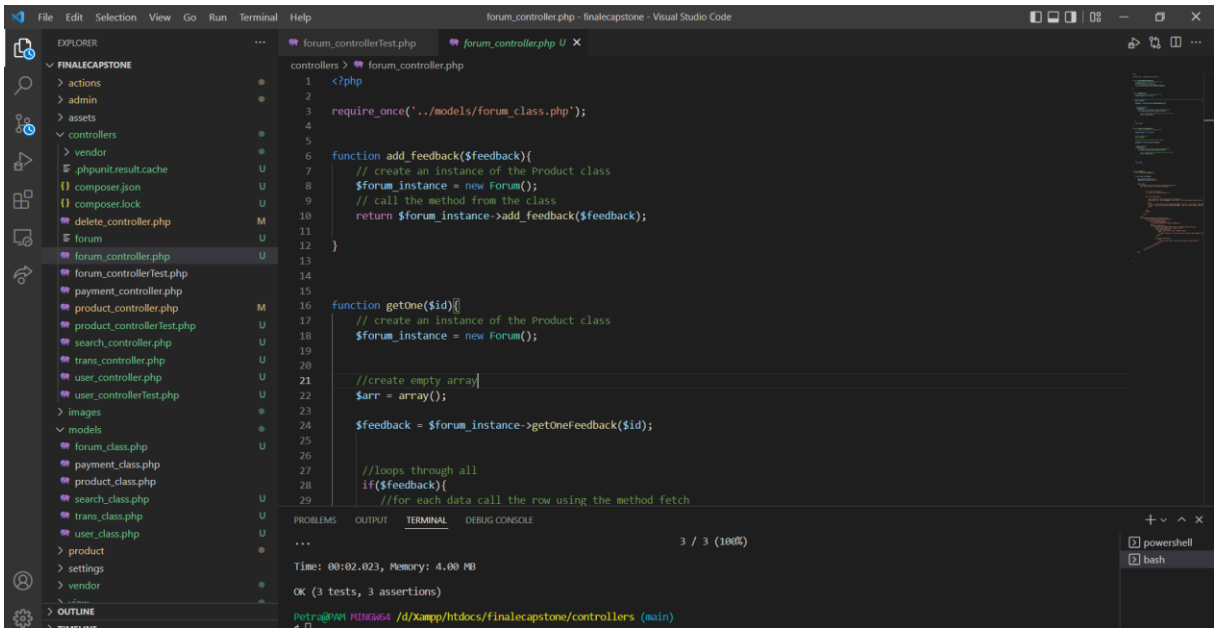

Figure 19: PHP Unit Testing of e-forum

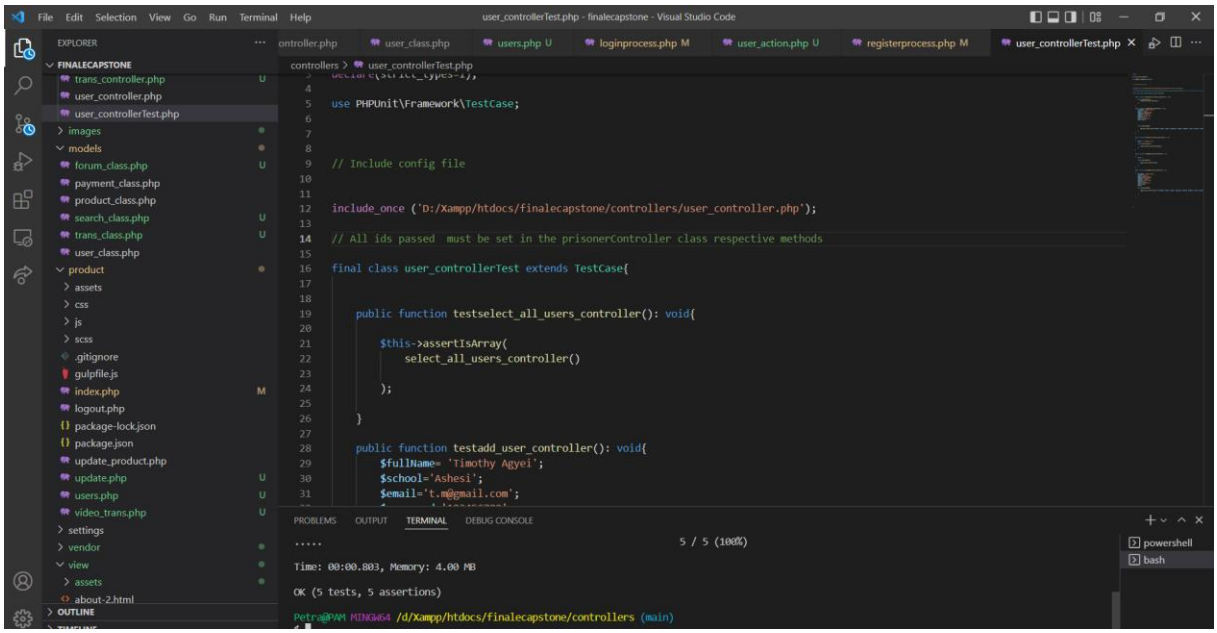

Figure 20: PHP Unit Testing for login

The unit testing enabled the correction and debugging of a few errors. For instance, the product controller gave an error because of a missing closing bracket, as seen in Figure 20.

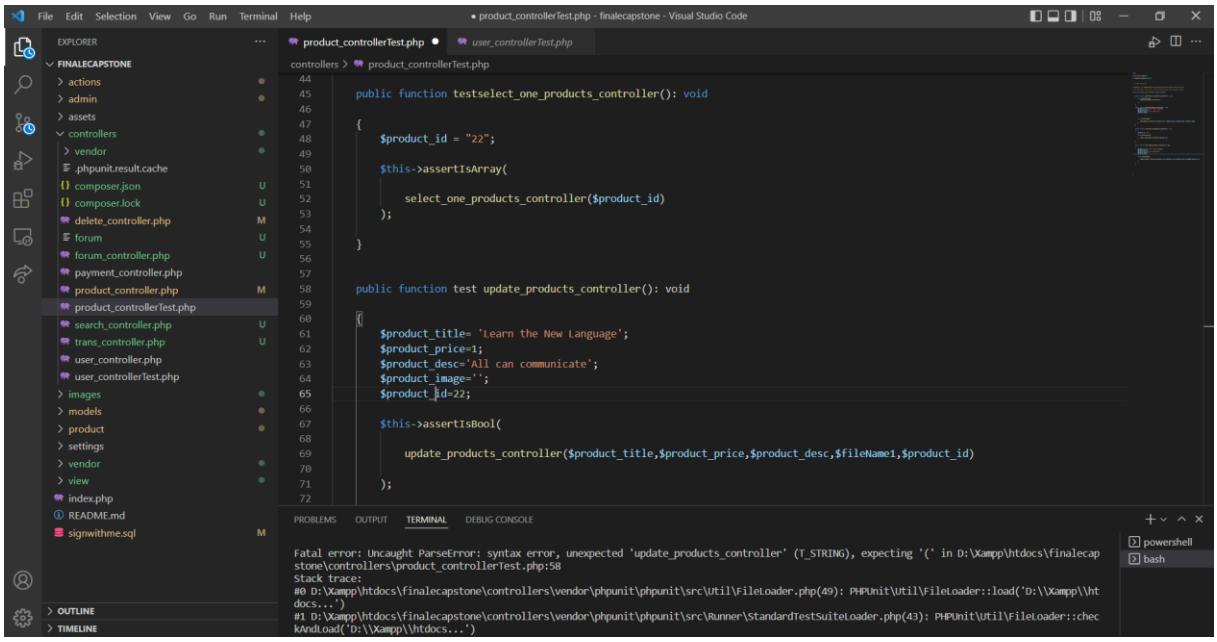

Figure 21: Snapshot of error due to missing closing bracket

Also, it enabled debugging a change in variable naming, as seen in Figure 21. Thus, the product_class id was named $product_id; however, in the product_class, it was named $id. Hence, through the testing process, the necessary corrections were made.

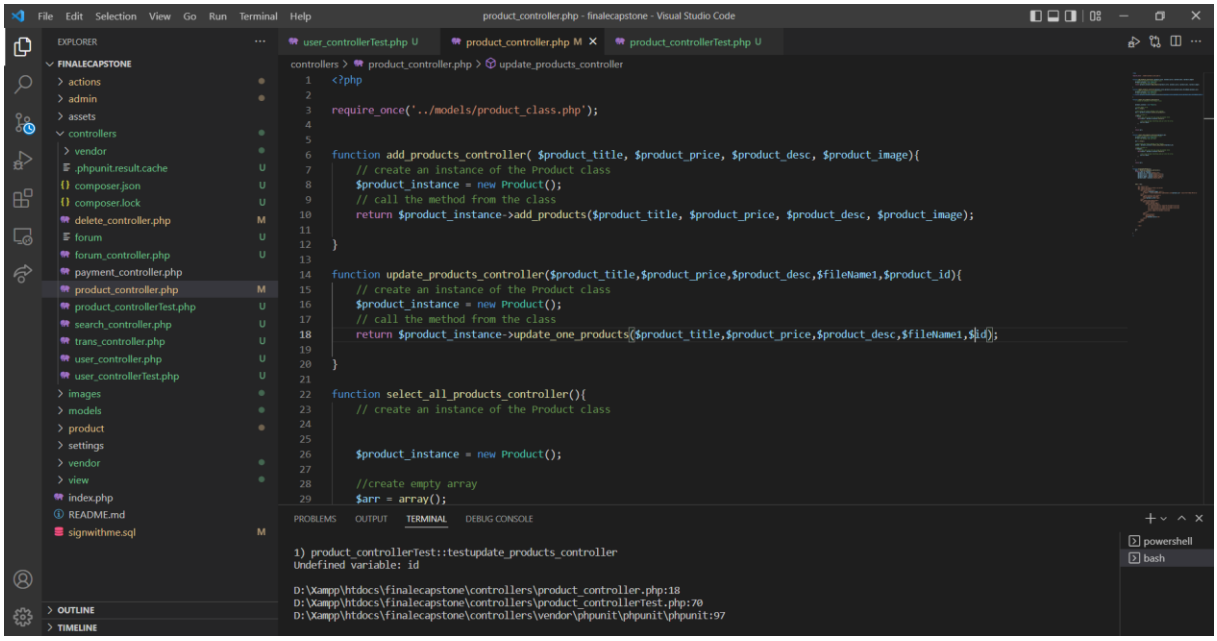

Figure 22: Snapshot of error due to variable naming

5.2 User Testing

The signWithMe application system was evaluated by ten Deaf students, two teachers at the Mampong School for the Deaf, and some students at Ashesi University. They gave important feedback that the application is easy to use and navigate. One Deaf student, Godfred, shared that the videos are short and demonstrate a particular sign, making it comprehensible. Belinda another Deaf student, shared that the system had bold and clear writings, making reading easier. The students were pleased with the explanation given on each of the signed words as it made learning more accessible. Also, the Deaf students looked through the signWithMe sign language dictionary and gave feedback on how some words should be signed.

They also shared that the system can be a mobile application to be accessed on the phone. A summary of the insights shared can be seen in Table 4.

Table 3: Insights from the User Testing

Participants	**Insights given by Participants**
Deaf Students at Mampong	• Navigating the website is convenient and easy. • Short videos make learning sign language comprehensible. • Writings are legible. • The application could be on a mobile application.
Teachers at Mampong	• General feedback is that the application system is interactive and efficient for teaching and learning sign language.
Students at Ashesi University	• Navigating and using the website is easy.

Figure 23: Testing the signWithMe Application System

Chapter 6: Conclusion and Recommendation

This final chapter emphasises the project's objective and summarises the implementation of the signWithMe application system. It explains some of the challenges encountered in building the application system and the future improvements that can be performed to make it more efficient.

6.1 Summary

There are many Deaf people worldwide, and there is a need for the Deaf and hearing to communicate amongst themselves to ensure harmony and inclusivity in society. As a result, the signWithMe application system was developed to provide a platform where both the Deaf and the hearing can learn and practise sign language. The application system is user-friendly and interactive. It uses bold words to express statements on the application system, videos, and pictures to express the sign words as the Deaf are primarily visual learners.

6.2 Limitations

This application system can be more advanced, especially with the sign language translator. Implementing a machine learning algorithm can allow users to interact more efficiently with the application system. Also, there is a need for a complete dataset to enable users to have a large pool of sign words to express themselves when communicating with the Deaf. Lastly, to ensure the system's availability, it must be hosted and made public for users. Due to the use of images and videos, which are dynamic data, the application system requires a hosting site that supports dynamic data. It must have a large storage size with resourceful computing devices to ensure the system is always running and readily available to users.

6.3 Recommendations

The signWithMe application system accomplished its goal of providing users with a teaching and learning platform. The application system efficiently provides functionalities and features that will help ensure users grasp the sign language content. Nevertheless, as stated in the limitations, machine learning algorithms can be implemented in some aspects of the application system, like the sign language translator, to ensure an efficient system translating sign words or phrases to users and vice versa. As per the insights shared by the Deaf students, a mobile application can also be created to enable users to access the signWithMe application system on their mobile phones.

Furthermore, there are numerous variations of sign language, as shown in Table 4. However, the Deaf community is advocating for an accepted sign language, the Ghanaian Sign Language (GSL), to ensure a common language that can be used to communicate with the Deaf. Also, this legal recognition of having a specific sign language will make it easy for Deaf people to access information, enhancing inclusivity and diversity in our society [21]. Sign language should be taught in the various primary schools in Ghana, like French and Ga, to ensure smooth communication between the Ghanaian community (Deaf and hearing).

Table 4: Various Sign Language in Ghana [17]

English Name	**Acronym**	**Alternative Names**	**Origin**	**Location of Use**
Adamorobe Sign Language	AdaSL	Mumu Kasa	Local	Village of Adamorobe, Ghana

American Sign Language	ASL	Ameslan, Langue des Signes Franco-Africaine	Foreign	Benin, Burkina Faso, Cote d'Ivoire, Ghana, Liberia, Mali, Nigeria, Togo, Mauritania
Ghanaian Sign Language	GSL	-	Based on ASL	Ghana
Nanabin	NanaSL	-	Local	Deaf family in the village of Nanabin, Ghana

In conclusion, bridging the communication gap between the hearing and Deaf in Ghanaian society through educational software is essential in ensuring the holistic growth of the Deaf community, especially with the Deaf children, as communication forms part of every child's growth. This project sought to provide an efficient and effective platform for learning the Ghanaian Sign Language.

This project aimed to provide educational software that will help teach and learn Sign Language and bridge the communication gap between the hearing and the Deaf in Ghanaian society. This was achieved by developing the signWithMe application system, which has subsystems such as the

- Sign Language Dictionary consists of videos on the primary sign language words—the alphabet, numbers, and days of the week.
- Sign Language Translator: this converts words to sign language. Thus, text-to-sign_language.
- Sign Language E-payment System: this enables users of the application system to purchase documents for learning.

- Sign Language E-Forum allows users to interact and share information about the Deaf and Sign Language.

The signWithMe application system was built based on web features. Web technologies such as HTML, CSS, Javascript, PHP and frameworks like Bootstrap and APIs were implemented in developing the signWithMe application system. The application system has functionalities and features such as the sign language dictionary, translator, e-forum, e-resources and e-payment system, which deliver a value proposition of a teaching and learning platform that aids users in their quest to acquire the sign language skill.

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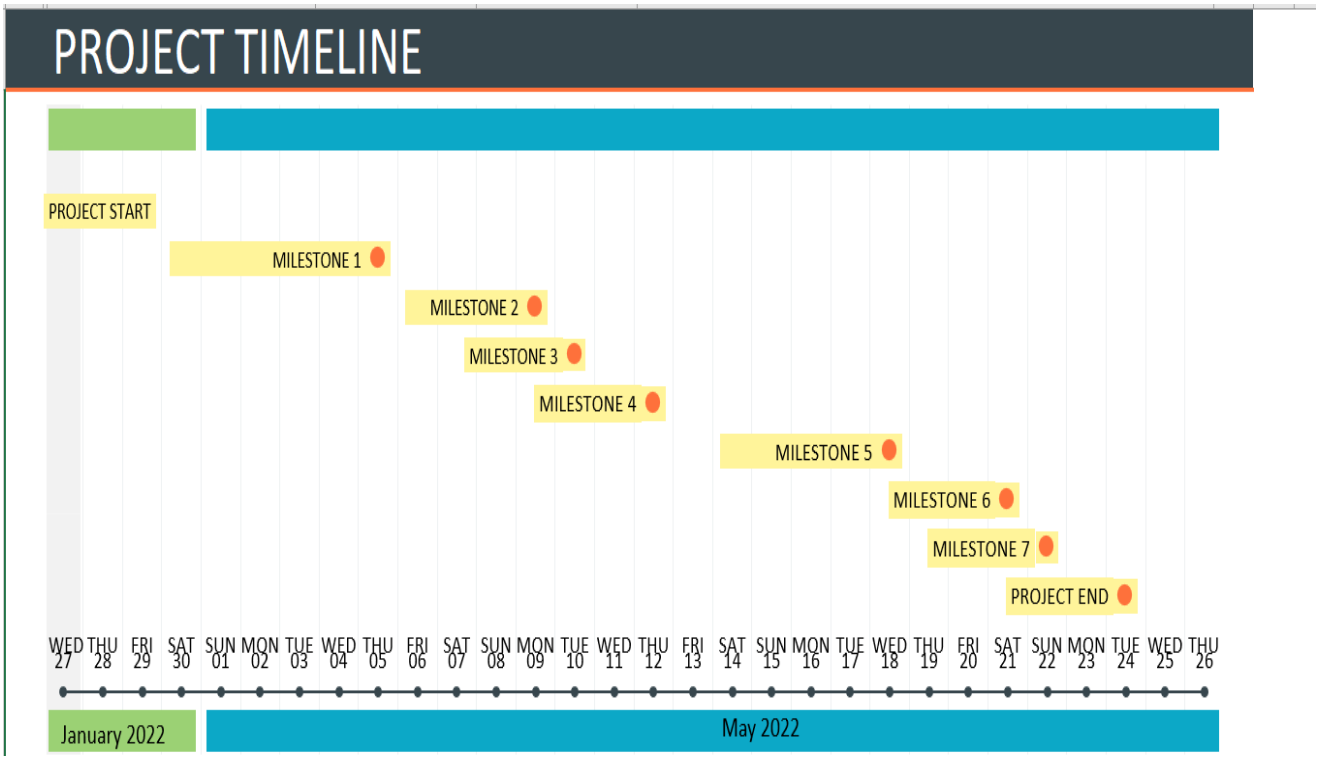
Appendices

Appendix A: Gantt Chart



ACTIVITY	START	END	NOTES
Project Start	01/09/2021	25/11/2021	Write up of Pre-proposal and Chapters 1, 2, 3 and some part of 4
Milestone 1	26/11/2021	12/31/2021	Conducted research with stakeholders
Milestone 2	17/12/2021	20/12/2021	Complete index page and login
Milestone 3	20/12/2021	22/12/2021	About us and contact page
Milestone 4	22/12/2021	25/12/2021	Building admin page
Milestone 5	26/12/2021	02/01/2022	Learning and building an E-forum
Milestone 6	03/01/2022	09/01/2022	Resources and e-payment system
Milestone 7	18/01/2021	31/01/2021	Dictionary
Milestone 8	02/01/2022	28/02/2022	Translator
Milestone 9	01/03/2022	30/04/2022	Final touches (admin page, hosting)
Project End	30/04/2022	01/05/2022	Reviewed final project (a complete capstone write-up and application deployment)

Appendix B: Interview Questions

DISABILITY RESEARCH INTERVIEW QUESTIONS ASHESI CAPSTONE 2021

PROJECT THEME: BUILDING AN INCLUSIVE AND INTELLIGENT LEARNING SYSTEM FOR PERSONS WITH DISABILITIES

DISCLAIMER: ALL RESPONSES TO THE QUESTIONS ARE ANONYMOUS AND CONFIDENTIAL AND WILL BE ONLY USED FOR RESEARCH PURPOSES. EACH RESPONDENT HAS THE CHOICE NOT TO ANSWER QUESTIONS THAT SEEMS TO BE CONFIDENTIAL OR PERSONAL TO THEM.
THANK YOU FOR ACCEPTING TO BE A PART OF THIS INTERVIEW

LINK TO SURVEY : https://forms.gle/tJmB85CMTcvbr2Cv6

SECTION A - INTERVIEW QUESTIONS

GENERAL QUESTIONS
Note: These questions are meant to give a better understanding of the respondent disability type

1. Would you want to be identified/classified as a person with [cognitive (ADHD, Dyslexia), mobility/motor, Vision loss, Hearing loss]?
2. Can you tell me about your [DISABILITY NAME]? (i.e., Vision loss, ADHD, Hearing loss, Dyslexia)
   Focal point (*for interviewer)***:** Extent – mild (blindness, colour blindness, low vision, visually impaired) to extreme
3. For how long have you had this disability (i.e., from childbirth or at some point in your life – accident, illness)? (Feel free to respond or not).
4. We would like to share the findings from our research and how your responses contributed to the research project. Would you like to share your email with us or any

COMMUNICATION QUESTIONS

Note: These questions are asked to understand the communication level of each respondent better

1. Tell me about how you communicate with others.
2. What are some of the challenges you face communicating with others?
3. Do you require any assistance when communicating with others? If yes, what kind of assistance do you need? Does it depend on the use of technology?
4. Tell me about a time you were misunderstood. How did you navigate that?
5. Have you had regretful experiences and encounters with people's attitudes? Tell me about it?

EDUCATION

Note: These questions are asked better to understand the education level and activities of the interviewees

1. Tell me about your educational experience? What were the achievements or challenges you faced in your journey?
2. Can you share some of the challenges you had faced in your learning journey in class and outside the classroom?
3. What level of education are you in?
4. How have you coped in your educational journey?
5. What are some of the challenges you have faced in your learning journey in and outside the classroom?
6. Are there any aids or modifications that make it easier for you to get an education, such as portable spell checkers, extra time for exams, or accessible classrooms? – *Tell me about such aids?*
7. How comfortable are you in speaking in a classroom discussion?

TECHNOLOGY

Note: These questions are asked to better understand existing technologies the interviewees have used, if any, what technologies they would like to use (if they have never used any)

8. Have you used any assistive technology in the past? What did you like about it? Was it useful? What do you wish could be better about it?
9. What other assistive devices for (DISABILITY TYPE) would you need to help you learn?
10. Does your current educational institution make it easy for you to learn?
    A. If yes, What structures are there to support you?
    B. If No, What are some of the provisions (e.g., devices, technologies) you hope to see in an educational institution to support you in learning?

    NB (*for interviewer***)**: Avoid leading/biased questions

11. Have you used any technological device in the past to support you in learning any material?
    A. If yes,
    i. Can you describe your experience with it?
    ii. Was it beneficial to you?
    ii. Is there any design flaws with the technology?
    iii. If yes, how can the technology better suit your need?

12. Do you use any assistive devices to help you get around or to accomplish other tasks?
    A. If yes,
    i. What tasks?
    ii. What are the devices that you use and their functions?

HEARING IMPAIRED PERSONS

1. Do you use any assistive devices to or communicate better?

A. If yes,

i). Which ones do you use?

B. If No,

i). Which are the assistive devices for hearing and communicating do you need?

2. Do you think you need other things to help you see and read better?

3. Do you have any dreams, aspirations?

A. If yes,

i). What are they, and what would you need(technological and emotionally wise) to accomplish them?

4. Do you know how to communicate with sign language?

A.If yes,

i).What is your level of proficiency?

B. If No,

i).Would you want to learn sign language?

5. If you have to use a sign language application

i). How would you want to be supported with a sign language application?

ii). What are some of the features you expect to see in the application?

iii). How useful will it be to you?

6. What kind of software solution would aid you in your learning? (Web-based, Mobile e.t.c)