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Master Thesis

Medical Teleconsultation System for Healthcare Professionals in Remote and Austere Environments

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Abstract

Access to quality healthcare is a privilege that many urban, well-connected communities enjoy, but providing the same level of care to remote and underdeveloped areas can be difficult. This is particularly true in areas with limited access to specialist knowledge and equipment. However, telemedicine has been shown to improve healthcare outcomes by enabling medical professionals to share patient information remotely and receive specialist advice and diagnoses. Studies show this can improve patient outcomes by bridging the gap between urban and rural healthcare access.

The Ministry of Public Health in Ecuador recognised the benefits that telemedicine services could offer, particularly in rural areas where access to medical specialists is lacking. In the late 2000s, the Ecuadorean government introduced the National Telemedicine/Telehealth Program which resulted in the launch of a pilot project focused on providing aid to doctors working in remote Amazonian communities as part of their mandatory rural service. A follow-up evaluation of this project by Dr. Leonel Adalberto Vasquez Cevallos resulted in the development of a web platform allowing doctors working in rural communities to submit patient information to receive feedback from specialist doctors. This web platform was later adapted by Dr. Vasquez Cevallos in collaboration with the Amigos de Cayapas Association to support doctors working in health posts in the rural communities of the upper Cayapas river in the Esmeraldas province.

Although the telemedicine web application worked well in supporting doctors working in the communities of the Cayapas river, feedback collected from the rural doctors expressed interest in the development of an Android application to facilitate teleconsultations in areas without internet access. This application would allow doctors to record and save teleconsultations in offline mode, and then upload the information once an internet connection becomes available. This would enable doctors to provide better care to patients in remote locations where internet connectivity can be unreliable or completely unavailable.

This Master's thesis presents the functional requirements, design, implementation, and evaluation of a web and Android application created as part of a telemedicine platform to provide telemedicine services to rural doctors working in the health posts of the upper Cayapas river. With support from the Amigos del Cayapas Association and the TEDECO group, testing and user evaluations were carried out on-site in these remote communities to assess the performance

of the platform. The testing and evaluation showed the telemedicine platform to be a technical success, however, there was poor adoption amongst the rural doctors who signed up to the platform with just one of the twenty-six registered doctors using the application to ask for clinical advice over the course of a four-month period. Further research and testing are needed to understand how a telemedicine platform can best support healthcare in indigenous and impoverished communities in remote locations.

Acknowledgements

I would like to express my gratitude to my supervisor, Dr. Ángel Herranz Nieva, for his invaluable guidance and technical support throughout the this thesis project. His technical knowledge and experience helped ensure both the web and Android telemedicine applications were technologically sound and used best practice solutions.

I would also like to thank my co-supervisor, Dr. Susana Munoz Hernandez, for first introducing me to the telemedicine project after I sent her an email asking for projects which could have a positive social impact. Dr. Munoz Hernandez' experience working on projects for developing communities was very helpful when finding solutions to the unique challenges involved in working in a developing community.

Likewise, I would like to thank the members of the Amigos del Cayapas Association, particularly Dr. Ana García Mingo and Paula de Corral San Martín, for their unwavering support during the design and development of the telemedicine project as well as during my time in the field amongst the communities of the Cayapas river. Without their support, this project would have been significantly more challenging.

The work described in this thesis would not be possible without the early research and work completed in the pilot telemedicine projects by Dr. Leonel Vasquez-Cevallos, for that reason I would like to thank Dr. Vasquez-Cevallos for providing vital insight gained from his experience on telemedicine projects in the past.

I would also like to show my appreciation to the communities of the upper-Cayapas river, particularly the community of San Miguel, for their hospitality and support during my 2-month stay in the region.

I would also like to thank the Universidad Politécnica de Madrid, for giving me the knowledge and skillset to complete this research project to a high standard. In particular, I would like to thank the TEDECO group and those supporting the TFT-CIDS program for awarding me the TFT-CIDS grant and supporting me in my work in the field in Ecuador.

Contents

Chapter 1

Introduction

This Master's thesis will focus on the design, development, and evaluation of a web application and Android application used to provide telemedicine services as part of a project carried out by the TEDECO group of the Universidad Politécnica de Madrid in collaboration with the Amigos del Cayapas Association. TEDECO is a specialised group that aims to use information and communication technology (ICT) to improve the lives of individuals and communities in developing regions. The Amigos del Cayapas Association is a non-profit medical association focused on improving the access to health care for indigenous and Afro-Ecuadorian communities living around the upper Cayapas river in the province of Esmeraldas, Ecuador.

In Ecuador, medical students are required to complete a year of service in a rural area as part of their Mandatory Rural Service before they can obtain their medical license. In their Mandatory Rural Service, the rural doctors do not have access to the equipment and specialist knowledge usually present in a city hospital. The work described in this thesis hopes to help provide rural doctors and medical students with a platform to send clinical cases to medical specialists who can then provide advice and suggestions on how best to treat the patient. The platform was developed so that queries could be made through an Android application that would communicate with an API hosted as part of the web application. With better access to specialist medical advice and assistance, the healthcare provided to the people in these indigenous and Afro-Ecuadorian communities can be improved.

1.1 Amigos del Cayapas Association

The Amigos del Cayapas Association was created in 2012 with the mission to improve access to healthcare for the indigenous and Afro-Ecuadorian communities in the upper Cayapas river in Ecuador. There are several challenges involved with providing healthcare to these communities, as the health posts are often understaffed and have insufficient medical supplies and any emergency cases require a 4-hour canoe ride to the closest hospital. Many of the communities around the Cayapas river do not have access to clean drinking

water and work within the communities often involves manual labour with tools such as machetes which can result in serious injuries, because of these living conditions, the communities in this region have been the subject of a telemedicine project run as part of the Amigos del Cayapas Association in order to improve the quality of healthcare provided.

1.2 History of the Telemedicine Project

In order to improve the quality of rural healthcare, the Ecuadorean government introduced the National Telemedicine/Telehealth Program in the late 2000s [1]. The program outlined three phases of implementation, each of which involved projects in collaboration with other private or public institutions. One of these pilot projects was the Tutupaly project which was started in 2007 by faculty at the Universidad Técnica Particular de Loja in collaboration with the Public Health Ministry of Ecuador [2]. The project involved general practitioners who were completing their Mandatory Rural Service in the Amazon rural area along with doctors at the University's faculty who responded to consultations submitted by the practitioners in these rural communities. The Tutupaly project involved work with seven health posts in the cantons of Yacuambi and El Pangui in the Zamora Chinchipe province. The health posts were provided with free access to technology to allow for video conferencing and teleconsultation forms which were exchanged electronically in the format of Microsoft Excel files [3].

A previous study on the use of a teleconsultation application supporting healthcare in rural communities in Peru found that the benefits of this technology could be extended to other Latin American countries if the teleconsultation services were tailored to meet the specific needs of local communities [4]. These suggestions prompted a follow-up evaluation of the effectiveness of the Tutupaly project through a variety of evaluation methods. The evaluation was led by Dr. Leonel Adalberto Vasquez Cevallos and included reviews of the technology, as well as questionnaires completed by both the general practitioners and faculty doctors involved in the project [3][5]. Using the information from this review as well as further investigation work in the communities, Dr. Vasquez Cevallos was able to develop technical specifications for a web application that facilitated communication between rural doctors and specialists by exchanging teleconsultations through the web platform. This platform was then validated through an evaluation with medical students who used the platform, the evaluation included a questionnaire issued to the participants. The evaluation showed that implementing the system for rural healthcare service in Ecuador would be feasible [3].

Following this, Dr. Vasquez Cevallos began work with the Amigos del Cayapas Association and adapted the application developed for the Tutupaly project to suit the needs of the telemedicine project for the Cayapas Telemedicine project.

1.3 Motivation

Although the telemedicine web application developed by Dr. Vasquez Cevallos was implemented and used by the doctors involved in the telemedicine project, the participants expressed interest in the development of an Android application to allow for teleconsultations to be recorded using only a smartphone. The development of an Android application that synchronises with a web application has the potential to allow the health workers working in rural communities the ability to complete teleconsultations without access to the internet and submit them to the web platform when internet access becomes available. Considering that many of the environments in which the rural doctors often work have limited or no internet access, having the capability to record teleconsultations offline has the potential to improve the impact of the telemedicine project for the better. As most Android phones are also equipped with a camera, support for Android devices also provides an easier method of including photos as supporting information for teleconsultations. Another feature that was requested by the participants in the first iteration of the telemedicine project was the ability to start a chat between the rural doctors and the specialists providing advice. Such a feature would allow follow-up questions from the rural doctors to clarify information with the specialist.

An Android application may provide value for the rural doctors working in austere environments, however, it is unlikely to provide similar value to the specialist doctors who do not have to deal with the same issues regarding internet access. As specialist doctors are likely to spend their time in locations with access to a computer and an internet connection, the platform for viewing and responding to teleconsultations would only be part of the web application and accessible by a web browser.

Chapter 2

Context

2.1 Ecuador

Ecuador, officially the Republic of Ecuador, is a South American country located in the northwest of the South American continent. The country is home to around 17 million people of many different ethnic and cultural backgrounds, with 71.9% of the population being categorised as mestizo, 14.4% Amerindian (also referred to as indigenous), 7.2% black, 6.1% white and 0.4% other [6]. Ecuador also has a large rural population, making up 36.2% of the population. This fact combined with the estimated 22.9% of the population classified as being below the national poverty line [7] helps give an idea of the barriers to quality healthcare for a large portion of the population.

Figure 2.1: Map of Ecuador highlighting the Esmeraldas province

Like many countries in the region, Ecuador's health care system is divided into two sectors: private and public. The public sector is made up of a comprehensive publicly-funded health system as well as national health insurance, this means that healthcare is available for free to all residents without any requirement to purchase medical insurance. The public health system is administered

by the Ministry of Public Health which acts as the national health authority and the guarantor of the right to health, whereas national health insurance is administered by the Ecuadorian Institute of Social Security.

2.1.1 The Esmeraldas Province

The telemedicine project is focused on the health center located in the village of Zapallo Grande as well as the surrounding health costs. Zapallo Grande is located in the Canton of Eloy Alfaro in the Esmeraldas province located in the north of the country (Figure 2.1).

According to the 2010 census, the Esmeraldas province has a population of 534,092 and the census stated that 78.3% of the population meets the poverty criteria established by the Unsatisfied Basic Needs indicator [8]. The province is divided into 7 cantons, the largest of these being the canton of Atacames in terms of population. Eloy Alfaro, the canton in which the project is focused, has an estimated population of 39,739 according to a 2010 census making it the second largest canton in the province by population.

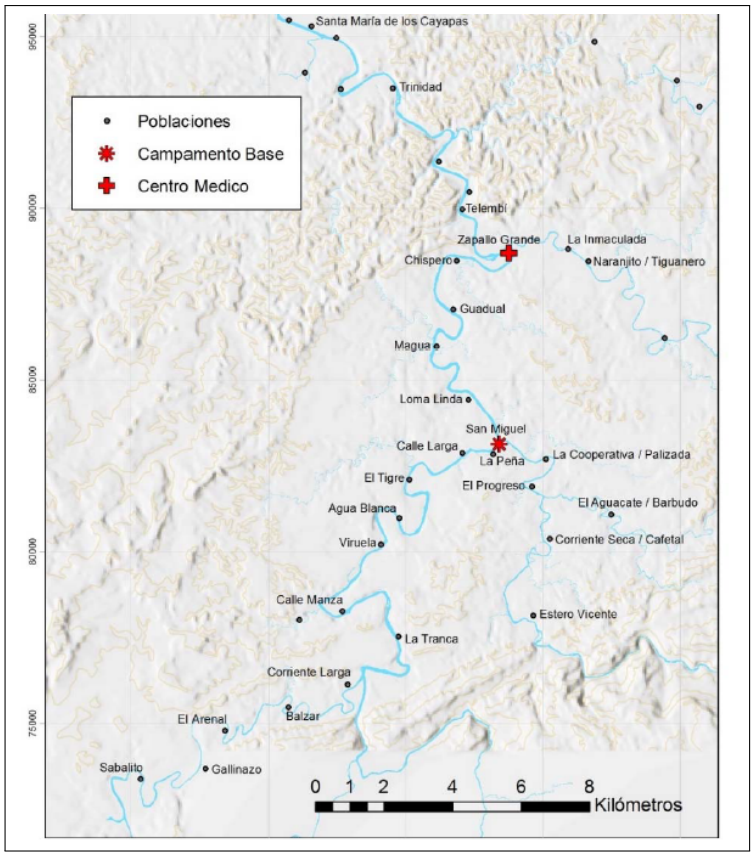


Figure 2.2: Map of the Zapallo Grande region and it's communities and health centers

Quality of Healthcare in Eloy Alfaro

The quality of the healthcare service in Eloy Alfaro is affected by several problems present in the area: a lack of adequate health infrastructure, healthcare professionals and specialists along with an insufficient supply of medicine. All of these problems have a detrimental effect on the health service provided to the population. Other infrastructural issues also affect the sanitary conditions in the region, poor sewerage and waste management and a lack of access to clean drinking water make maintaining good sanitary practice difficult for a large number of the population.

Although Eloy is home to over 500,000 inhabitants, there are only two hospitals available to the population, located in Limones and Borbón, the number of hospital beds between the two hospitals add up to a total of just 40 [8].

Zapallo Grande

The communities and rural doctors involved in the telemedicine project are served by a health centre located in the village Zapallo Grande on the Cayapas river. Zapallo Grande is responsible for providing healthcare services to communities situated around the mid-to-upper part of the Cayapas river, along with the communities around two tributaries of the river: the Zapallo river and the San Miguel river (Figure 2.2). A small number of health posts are also available in the surrounding communities, such as the one in the nearby village of San Miguel, however these health posts are much smaller and are typically only staffed by just one or two doctors, this means that they are only equipped to offer very basic medical services.

2.1.2 Background of Telemedicine Services in Ecuador

There have been a few attempts at starting telemedicine projects in Ecuador, start by both public and private institutions. The earliest attempt at starting a telemedicine project was in 2002 by Maria Teresa Mijares who developed a 5 year plan to increase the use of telemedicine in the country, however, the project has trouble getting started due to a financial crisis in the country [9]. In the latter half of the 2000s however, the government of Ecuador introduced the National Telemedicine/Telehealth Program, with one of the pilot projects in the early implementation phases of the program being the Tutupaly project started in 2007 [1]. Following on from the Tutupaly project, the Ecuadorian government sought to expand telemedicine throughout the country between 2012-2014, this expansion however, was unfortunately deemed unsuccessful [10].

Chapter 3

State of the Art - Telemedicine

Telemedicine has many different definitions, The World Health Organisation defines telemedicine as "The delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities" [11].

As technology has progressed, many healthcare services that were traditionally only offered in person have moved onto digital platforms, this along with widespread access to the internet has led to healthcare services being offered through a telemedicine platform. Although telemedicine has its limitations, it provides a particular advantage in situations where in-person meetings are difficult or impossible. This was particularly relevant during the COVID-19 pandemic as many were required to quarantine, restricting their access to necessary services, a study that reviewed the literature related to telemedicine during the pandemic showed that there was a rapid increase in the use of telemedicine service during the period, showing that such services can prove valuable under certain conditions [12].

Telemedicine has the potential to offer benefits to both patients and doctors, perhaps the most obvious of these is providing easier access to medical services for patients as distance is much less of an obstacle when offering services that can be provided via a video call.

3.1 Categories of Telemedicine

Telemedicine services typically fall into one of three main categories: Remote patient monitoring, Store-and-forward, and Real-Time Audio/Video Communication.

3.1.1 Remote Patient Monitoring

Remote patient monitoring is a form of telemedicine which allows healthcare professionals to monitor the health of patients as well as obtain clinical information remotely. This reduces the cost of frequent check-ups on patients and also has the potential to improve patient compliance with testing. Remote patient monitoring is often used when treating or managing patients with chronic illnesses such as diabetes, cardiovascular disease, and asthma [13].

3.1.2 Store-and-forward

Store-and-forward typically involves the collection of clinical information and sending it electronically to another location for evaluation. An example of this might be a doctor sending images of an x-ray to a radiologist for analysis, this process would be considered store-and-forward telemedicine. Store-and-forward is not just limited to images, it could include any type of information such as medical history, videos, lab reports, etc. Store-and-forward is one of the older types of telemedicine, but it has the potential to provide value to patients and healthcare providers by eliminating the requirement of a general practitioner and a specialist to be present with the patient at the same time. Some NGOs have found using a store-and-forward telemedicine system to be an efficient and reliable method to support healthcare in remote areas [14].

3.1.3 Real-Time Audio/Video Communication

Real-time communication usually involves a patient and a healthcare professional communicating with each other remotely through a video conferencing system or computer audio call. If a patient is unable to travel to a local health provider, then communication with the patient may occur via a video call, this would be an example of real-time communication telemedicine. Real-time communication is not just for communications between professionals and patients, it may also describe an interaction between a general practitioner and a specialist in a remote location [15].

3.2 Differences between Telemedicine and Telehealth

Although the terms telemedicine and telehealth are often used interchangeably, they typically refer to different things.

Telemedicine typically involves some form of communication between patient and doctor, or doctor and doctor. This could include things such as diagnosis, live feed monitoring or forwarding of patient test results to specialist doctors. Some less common practices which fall under the definition of telemedicine are telementoring, where a more experienced medical professional would oversee the procedure completed by a less trained individual and robotic surgery, where surgery is performed with the use of robotic tools or devices.

Telehealth on the other hand has a broader scope and includes nonclinical

services such as administrative work and tele-education for patients or healthcare providers. Telemedicine can be thought of as a being subclass telehealth, with telemedicine being encompassed by telehealth. Telehealth might involve analysing some of the barriers to implementing a telemedicine solution such as assessing the training or technology required to introduce a new service [16].

3.3 Telemedicine between professionals

As mentioned previously, telemedicine not only allows for healthcare services to be provided to patients by healthcare professionals, there is also the advantage of sharing useful information between healthcare professionals. The overwhelming majority of cross-border telemedicine services are designed to link health professionals together with services linking professionals and patients being the exception [17].

Telemedicine can improve the effectiveness of treatment and diagnosis by allowing professionals to exchange important information such as the history of the patient, results from any previous tests as well as any concerns the patient might have expressed [18].

3.4 Teleconsultation

Teleconsultation describes the interaction between a healthcare professional and a patient with the purpose of providing medical, diagnostic or psychiatric advice using a communication medium enabled by information technology. Studies have shown that the introduction of teleconsultation into the world of health care has helped significantly reduce the number of required face-to-face visits between patients and professionals [19] as well as provide practical and cost-effective ways of providing worthwhile health care services to patients [20].

Chapter 4

Initial State of the Cayapas Telemedicine Project

As mentioned in section 1.2, the Cayapas telemedicine project started with a web application developed by Dr. Vasquez Cevallos. One of the technical requirements of this application was that it be developed using a licence-free and open-source framework, for this reason, the Joomla framework was chosen for development [3].

The work carried out as part of the Telemedicine project has resulted in the development of a few different applications for use by the medical professionals and students working in the Cayapas region. The first of these was the Telemedicina-CAYAPAS web application developed using Joomla.

Figure 4.1: Joomla web app - New teleconsultation page

4.1 Telemedicine in Cayapas - Joomla

The Telemedicina-CAYAPAS web application was developed using Joomla, Joomla is an open-source content management system used to create web applications. The application was designed to be used by two different types of users described as Rural Doctors and Specialist Doctors with coordination of these users carried out by a Coordinator user. At the time of this analysis, the system allowed rural doctor users to log in and submit details of teleconsultations with patients to the platform for feedback from specialist doctors. Rural doctor users would be presented with a form to enter patient details as well as the type of specialist from which feedback is to be requested, relevant files such as images or documents could be added to the form before submission. This version offered the ability to import and export teleconsultations to allow for local storage when the internet is unavailable as is often the case in these remote communities, although internet access would be required to access the web page in the first place. Once submitted, users with the specialist doctor role could provide advice and suggestions on the teleconsultation submissions relevant to their field of expertise, this might include information such as patient diagnoses or recommendations of medicine to be given to the patient.

4.1.1 Database schema

The database schema for the Joomla application was not formatted well, however, it was possible to extract some general data models for teleconsultations and specialist responses. These data models were originally generated based on the Ecuadorian Ministry of Health's guidelines for consultation documentation [21].

- **Affiliation data**
  - **Code:** Unique code automatically generated upon creation of the teleconsultation.
  - **Rural doctor:** The doctor who carried out the consultation with the patient
  - **Date:** Date the teleconsultation was submitted
  - **Province:** The province the rural doctor was in for the consultation.
  - **Canton:** The district the rural doctor was in for the consultation.
  - **Parish:** Indicates the parish in which the doctor is located. As this refers to isolated areas of the city, this field will only apply to rural doctors.
  - **Operative Unit:** The health center or post in which the rural doctor completed the consultation.
  - **Speciality:** The type of specialist that advice is required from.

  - **Specific data of the clinical case:** Information specific to the patient such as sex, age, ethnicity, etc.

- **Reason for consultation:** The reason that the rural doctor is carrying out the consultation.
- **Medical history**
  - **Peri-natal:** Any information relevant to a patient's pregnancy
  - **Diseases of interest:** Prior conditions such as diabetes or hypertension.
  - **Surgical:** Any information relating to previous or future surgeries.
  - **Obstetrics and Gynecology:** Information related to a woman's reproductive health
  - **Allergies:** Any allergies the patient suffers from.
  - **Family medical history:** Information on the medical history of the patient's relatives
- **Current disease:** A description of current disease or reason for consultation
- **Complementary tests:** These could be tests such as blood tests, sputum analysis, EKG, radio-graphic films, etc.
- **Physical Examination**
  - **Weight:** The weight of the patient in kilograms.
  - **Height:** The height of the patient in centimeters.
  - **Heart rate:** The measured heart rate of the patient in beats per minute.
  - **Systolic blood pressure:** The measured systolic blood pressure of the patient in mmHg.
  - **Diastolic blood pressure:** The measured diastolic blood pressure of the patient in mmHg.
  - **Temperature:** The recorded temperature of the patient in degrees Celsius.
  - **Respiratory rate:** The recorded respiratory rate of the patient in breaths per minute
  - **Pain:** The self reported pain by the patient on a scale from 1 to 10.
- **Probable Diagnoses**
  - **3C Code:** The "3 Character code", this is a code selected from the International Classification of Diseases (ICD) classification system created by the WHO. The rural doctor would select a code that they thought was the most probable diagnosis for the patient.

  - **3C Sub-code:** The ICD classification system also allows for sub-codes to provide more specific information. This is what the rural doctor would specify here.
  - **Additional description:** Any other information related to the the probable diagnosis the rural doctor believes to be relevant.
- **Comments and questions:** Any comments or questions related to the consultation from the rural doctor.
- **Attached files:** Supporting files related to the consultation, such as photos.

4.1.2 Format of a Specialist Response

The following format was generated based on the Ecuadorian Ministry of Health's guidelines for consultation documentation [21].

- **Affiliation data**
  - **Code:** Unique code automatically generated upon creation of the response.
  - **Specialist doctor:** The specialist doctor who is making the response
  - **Date:** Date the response was submitted
  - **Province:** The province of the specialist
  - **Canton:** The district of the specialist
  - **Parish:** Indicates the parish of the specialist
  - **Operative Unit:** The health center or post of the specialist
- **Comments:** Comments from the specialist on the consultation
- **Presumptive diagnosis:** A presumptive diagnosis of the patient from the specialist.
- **Definitive diagnosis:** The definitive diagnosis of the patient from the specialist.
- **Therapeutic plan:** A proposed therapeutic plan to treat the patient
- **Educational plan:** A proposed therapeutic plan to treat the patient
- **Attached files:** Any files related to the response, such as photos, medical documents or presentations.

Figure 4.2: Registration page of new web application

4.2 Elixir Web Application

Following the development of the Joomla application, it was decided that a new and updated application would be created to work in conjunction with an Android application. The new application would use an API hosted on the web application to allow for seamless communication between the two platforms. The project was started as part of an end of degree project by a fellow student of the Universidad Politécnica de Madrid, Carlota Miñaca Paul[22]. This new application was started development using the language Elixir with the Phoenix framework as this approach is well suited for scalability. Elixir is a functional programming language built on the Erlang language which is regarded as being highly fault-tolerant and offering low-latency execution. The Phoenix framework uses a model-view-controller (MVC) pattern which allows for clearer separation of user interface, database and logic to deal with user input.

4.2.1 State of Development

The web application was left in a relatively early stage of development, the latest version allowed users to register an account and log in to the application and perform a few other user account related tasks. However, no work allowing users to perform any other task such as viewing teleconsultation information or for specialist doctors to give advice had been developed.

Front-end

In terms of the front-end of the application, a simple welcome page had been developed, as well as pages for:

- **User registration**

  Users need to enter an email, password and their role (rural doctor, specialist, or coordinator)

- **User login**

Allowing users to login using their email password

- **User settings**

  Allowing users to change their email or password (requires user to be logged in).

- **User email confirmation**

  Used to send a confirmation email to the user so that they can confirm their email address.

Development of the pages necessary to display teleconsultation information as well as a page allowing specialists to provide feedback had yet to be completed.

API

The web application had no exposed API endpoints.

Database

The database of the application was created using the Ecto database library for Elixir, which is used to interact with a Postgres SQL database. The latest version of the application only had a database containing one table 'users', which contained the user information. The table contained the following fields:

- id: Unique code associated with each user (type *int*).
- email: Field of type *String* which contains the email of the user
- hashed_password: Field of type *String* which contains the hash of the user's password.
- role: Field of type *String* which represents which role the user has (rural, specialist or coordinator)

4.3 Android Application

Figure 4.3: List of teleconsultations as displayed in the Android app

During the original development of the new web application, an Android application was developed to communicate to the web application via the API. The Android application needed to offer similar functionality to the origina Joomla web application, allowing users to enter teleconsultation information including the patient details and any relevant files or photos.

4.3.1 State of Development

The Android application was in a much more developed state than the new web application. The latest version had a UI which allowed users to view, create, edit, delete and save teleconsultations to be stored locally on the phone. As the web API functionality had yet to be developed, the application was only able to manage teleconsultations locally which meant the ability to send and receive teleconsultations to the web application as well as user registration and log in had not been tested, however early code to achieve these functions had been written.

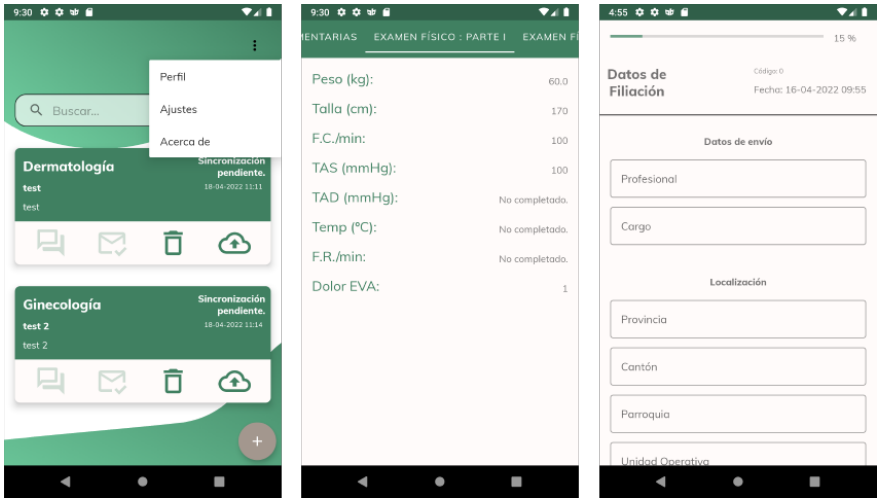


Figure 4.4: Interfaces for the menu, viewing and creating teleconsultations

After logging into the application, the user was presented with the main page which showed a list of teleconsultations stored in the application. From this page, the user was able to select the three-dot menu to select between the options of viewing the user's profile, adjusting the app settings (here the user could select between a light or dark theme) or read more about the application and telemedicine project.

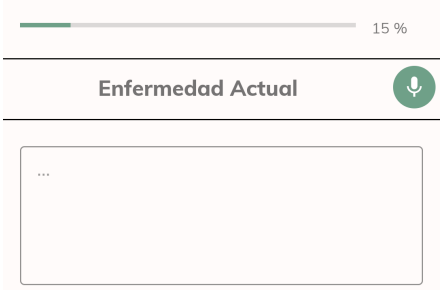


Figure 4.5: Field input allowing for microphone input

In order to create a new teleconsultation, the user could touch on the '+' at the bottom right of the screen. This would take the user to the teleconsultation creation page, where they would be presented with several fields to fill with information related to the teleconsultation. For fields that may require a large amount of text, a microphone button allowed users to make use of Google speech-to-text services to record the user's voice and transcribe their words into written Spanish in the corresponding field (Figure 4.5).

Each teleconsultation created was stored locally in a lightweight database on the user's smartphone. A list of stored teleconsultations was shown on the main page of the application, users could view the details of a specific teleconsultation by touching on it (Figure 4.3). Buttons on each teleconsultation allowed a user to

upload or delete the teleconsultation as well as read a response from a specialist. There were also interfaces developed in order to view the response sent from a specialist, however as there was no web application to create these responses, this had yet to be tested.

4.3.2 Database Schema

Figure 4.6 shows the database schema of the Android application in its initial state, the data models mostly follow the models extracted from the Joomla application shown in section 4.1.1. As the web application database and API hadn't been developed yet, many fields were undefined. Field names were written in Spanish, but the majority of the Spanish names were direct translations of the properties described in section 4.1.1.

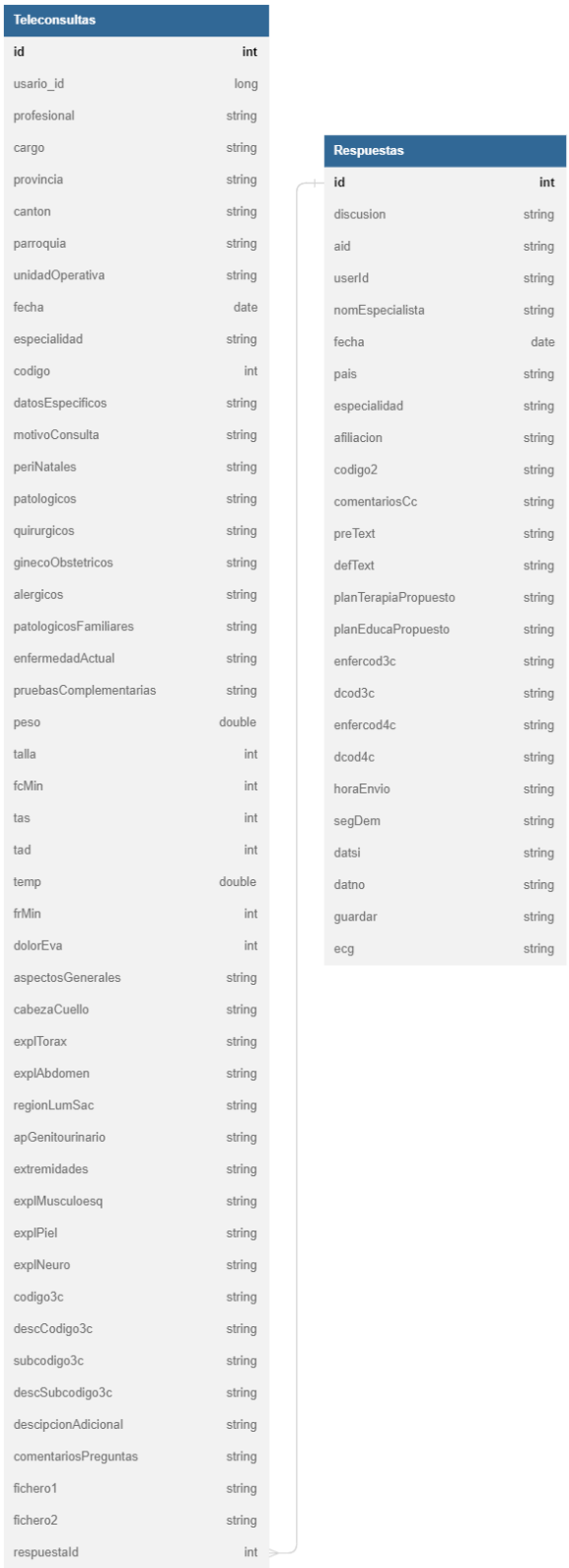


Figure 4.6: Initial Database Schema of Android Application

Chapter 5

Software Engineering Practices for the Telemedicine Project

As the telemedicine project will be used in a medical context involving sensitive patient information, it was important that the software engineering practices applied to the project conform to the recommendations in the state of the art in the field.

5.1 Software Life-cycle

The software life-cycle, also referred to as the software development life cycle (SDLC), typically refers to a methodology describing how a software project will be developed through a series of defined processes or phases of development. A software life-cycle methodology typically outlines how a project will be developed starting with the requirements phase all the way through until the implementation and testing of the project [23].

5.1.1 State of the Art

There are many schools of thought around software life-cycles; three of the most prevalent methodologies used in the state of the art are the Waterfall, Iterative and Agile models [24, Chapter 8].

- **Waterfall**

  The waterfall model is considered one of the more traditional and less flexible software life-cycle models. It is called the waterfall model as it dictates that progress should flow in one direction through each phase of the project. In practice, this means that the design phase could not be started until after the requirements phase had been completed [25].

- **Iterative**

  The iterative model was developed to overcome the rigid structure of the waterfall model, as the name suggests it suggests that development occurs

in a series of repeated cycles or iterations. The iterative model begins with the requirements phase followed by a series of mini-waterfalls with each iteration following a linear process from design and development to testing and implementation [26].

- **Agile**

  The agile model takes the iterations of the iterative model but has a higher focus on adaptability and customer satisfaction. Whereas the waterfall and iterative models adhere to a structure which relies on requirements being defined early in the project and any changes being incorporated through a strict change control management process. Agile on the other hand uses an adaptive approach which has less detailed planning, with tasks being defined only by what features need to be developed [27].

5.1.2 Life-cycle for the Telemedicine project

As requirements for the web application and Android application were based primarily around features to be developed, the agile life-cycle model was determined to be the best choice for development. Weekly project progress meetings provided the perfect environment to plan iterations.

5.2 Requirements Elicitation

Requirements elicitation described the activities involved in discovering requirements, this could be in the form of interviews, document analysis or prototyping. The goal of requirement elicitation is to extract not only the functional requirements for a project, but also nonfunctional requirements such as expectations of quality or availability from the appropriate sources.

5.2.1 State of the Art

In the third chapter of their book *Software Requirements*, Karl Wiegers and Joy Beatty recommend the following activities as good practice when eliciting requirements for a software project [28, Chapter 3]:

- **Focus groups**

  Eliciting requirements through focus groups involved organising groups of representative users of similar products and collecting their input on both the functional and quality characteristics. Focus groups are a good option when a product has a large and diverse customer base.

- **Elicitation interviews**

  Elicitation interviews can involve one-on-one conversations or a talking with a small group of project stakeholders, as interviews are directly structured around discussing specific requirements; this elicitation method is time effective.

- **Questionnaires**

  Questionnaires are a good option when there is a desire to survey a large group of users to understand their needs in relation to the project. With well written questions, a questionnaire can help provide quantitative data about user needs.

5.2.2 Requirements Elicitation in the Telemedicine Project

The stakeholders in the telemedicine project include: the rural doctors and specialist doctors that will be working with the teleconsultations, the members of the Amigos de Cayapas Association, and the members of the TEDECO group who are involved in the Cayapas telemedicine project. Communication with the rural and specialist doctors is limited as there are many of them and they are typically busy working, however the members of the Amigos de Cayapas Association have higher availability and work closely with said doctors and are therefore in a good position to represent their interests. As the members of the Amigos de Cayapas Association and TEDECO are few in number, elicitation interviews were the ideal method for eliciting requirements for the project. These interviews were possible through the video conferencing tool Zoom, which removed the need to conduct in-person interviews.

As mentioned in section 5.1.2, the decision was made to follow an agile software life-cycle model for the project, for this reason the requirements elicited through the interview process were not considered fixed and were treated as adaptable depending on the needs of the project stakeholders throughout the project. However, it was still important to have a record of the functional and nonfunctional requirements of the project in order to generate the task list for the project.

5.3 Testing

As the intention for the project was for rural doctors to record patient details using their Android device when there is little access to other technology, it was important that the software be tolerant to failures and bugs.

5.3.1 State of the Art

Approaches to Functional Testing

- **Static and dynamic testing**

  Static and dynamic testing describe two contrasting methods to test a piece of software, static testing occurs when a developer proofreads their code to check for bugs, this can also be done by programming development environment tools and extensions. Dynamic testing on the other hand requires that the program be running, here the tester can feed inputs into the running software to try and find any bugs [29, Chapter 11].

- **White and black box testing**

  White and black box testing refers to two techniques used to generate test cases. White box testing is a method of generating test cases for a piece of software based on knowledge of the internal structure of the code, whereas in contrast, black box testing involves generating test cases without looking into the internal structures of a piece of code [29, Chapter 3].

Levels of Functional Testing

- **Unit testing**

  Unit testing involves the testing of smaller sections of code such as methods or classes through the development of automated tests that confirm whether a section of the code is working as expected. In order to write unit tests, knowledge of the code that makes up the functions or classes to be tested is required (i.e. the white box approach). Unit tests are typically quick to write and quick to execute [29, Chapter 11].

- **Integration testing**

  Integration testing involves testing how components interface with each other. It is typically carried out on parts of the system that have been validated using unit testing, integration testing is then carried out when these components are connected together. Integration testing typically takes significantly more code to be written to be completed effectively [29, Chapter 11].

- **System testing**

  System testing is typically carried out on a system that is fully integrated in order to determine whether it meets the system requirements. This might involve going through the process of logging in to a system, performing a task and logging off [29, Chapter 11].

5.3.2 Functional Testing of the Telemedicine Project

The functional testing of both the web application and Android application used both static and dynamic testing throughout the development of the application. Test cases were generated at a system level based on the functional requirements, these test cases were generated without taking into account the internal structure of the code (black box method).

5.4 Software security

Due to the sensitive nature of the information that was to be stored and transmitted in the project, keeping this data private and secure was of vital importance. For this reason, it was necessary to understand what security risks the applications may be vulnerable to and what the state-of-the-art recommendations are to prevent said risks.

5.4.1 Security Risks of the Telemedicine Project

The field of software security is broad and covers many different vulnerabilities that a program may be subject to, however the following are the vulnerabilities that were identified as being most likely to result in a security risk in the telemedicine project.

- **SQL injection**

  An SQL injection attack attempts to issue queries to a database through inputs to a web or mobile application. This might involve writing an SQL query into an username or email input in order to manipulate or read data from the database that the user should not have access to. Seeing as both the web and mobile applications had their own databases, the risk of SQL injection needed to be addressed [30, Chapter 5].

- **Malicious file uploads**

  As the web application had the feature of attaching files to teleconsultations and responses, there was a risk of an attacker uploading a file containing malicious code in, the form of an executable which was identified as having the potential to expose private data [31].

- **Brute force attacks**

  A brute force attack is an attack in which a malicious party inputs multiple passwords in an attempt to eventually guess a correct password [32]. As users were able to log in using both the Android and web applications, the risk of an attacker brute forcing their way into the system by attempting to guess a user's password needed to be.

- **Man-in-the-middle attacks** A Man-in-the-middle attack involves a malicious party secretly monitoring and perhaps modifying the communications between two entities by the attacker inserting themself between the two entities in the line of communication. This attack allows an attacker to gain access to a user's username, password, or any other sensitive data transmitted through client-server communications [33]. As users were required to log in to the application by providing an email and password, there was the potential for a malicious third party to view the communications between the client and server to sniff out this sensitive information and perhaps gain access to a user's account.

5.4.2 State of the Art

- **SQL injection prevention**

  SQL injection attack prevention methods depend on the language and database engine used in a software project however most SQL injection attacks can be prevented through input validation and parameterised queries with prepared statements.

Input validation involves verifying whether user submitted inputs are allowed, this might mean rejecting user inputs that contain single quotes.

Parameterised queries are a method of pre-compiling an SQL query with supplied parameter values as inputs before the query is executed [34].

- **Malicious file upload prevention**

  Having restrictions on the file extensions that a file uploading platform allows can prevent potentially malicious files from being uploaded to the platform. For example, restricting file extensions to just .JPEG and .PNG to only allow users to upload image files.

- **Brute force attack prevention**

  There are several methods that can prevent brute force attacks to an application, however a couple of the more widely used methods are locking out accounts after failed log in attempts and using CAPTCHA [35].

  Brute force attacks can be prevented by locking out an account after a predetermined number of unsuccessful log in attempts, the lock out should last for a predetermined amount of time before another log in attempt can be attempted.

  CAPTCHA is a tool that requires a user to complete a task that is designed so that it can only be completed by a human. Using CAPTCHA can be highly effective against bots but can have a negative impact on the user experience.

  The hashing function used to hash user passwords can also make applications resilient to brute force attacks. If the amount of work required to hash a password is significant, the hashing process is slowed down; this prevents an attack from guessing passwords millions of times per second [36].

- **Man-in-the-middle attack prevention**

  One of the most effective ways to prevent man-in-the-middle attacks is by using SSL (Secure Sockets Layer) and only allowing access to the web application through HTTPS. Using SSL will ensure that any data exchange between the client and the server is secure [37].

5.4.3 Software Security in the Telemedicine Project

Several measures were taken to mitigate the potential security risks of the project. As the web application exclusively uses the Ecto database toolkit to interact with the database, there was no risk of SQL injection. This is because Ecto always uses parameterised queries, so user inputs can never enter the SQL string directly. The Android application was developed using the ObjectBox library for its local database operations. As ObjectBox is a NoSQL database solution and uses an API instead of a query language, it is not vulnerable to injection attacks.

To mitigate malicious file uploads, file uploads via the web application use an extension 'whitelist' to only permit the extensions: .jpg, .jpeg, .gif, .png, .pdf, .doc, .docx, .ppt, .pptx whereas the Android app is only capable of uploading .jpeg files taken from the Android gallery, or via the camera.

User authentication in the web application uses the Bcrypt hashing function to hash user passwords, the "cost" of hashing user passwords can be increased by using a longer salt. A salt is a random string that determines the unpredictability of the hash. The hash function used in the web application used the default salt with a computational cost of 12 rounds (2^{12} iterations). This cost should be sufficient to make the application resilient to brute force attacks [38].

The web application was hosted on the TEDECO web servers which enforce an HTTPS connection, any attempts to access the URL using HTTP are redirected to the HTTPS address. This ensures that data exchange between client and the server is secure from man-in-the-middle attacks.

5.5 Usability Testing

To identify any issues for the intended users of the telemedicine project, it was important to evaluate the usability of both the web and Android applications through the use of usability testing.

5.5.1 State of the art

Moderated vs unmoderated

Usability testing can be performed in a moderated or unmoderated setting. Moderated usability testing would involved a live session with the participant, whereas an unmoderated usability test would not have a moderator.

Conducting a live moderated test with a user allows the opportunity to gain a deeper understanding of the user's perspective through the use of probing and follow-up questions as well as offering the benefit of see the exact paths the user follows to complete particular tasks. Moderated testing however, takes a significantly longer amount of time and therefore can only be used with a smaller sample size.

Unmoderated testing on the other hand can take advantage of much large sample sizes due to the lack of moderation for each user's test. It also allows for much faster feedback response times as well as being less time intensive to manage [39].

Usability Test Scripts

Usability test scripts is a pre-written script that a moderator follows during a usability testing session with a participant. It typically consists of a brief introduction, some basic warm-up questions, some tasks to be carried out by the participant followed by some wrap-up questions and closing words.

Usability test scripts are useful as they allow the moderator to keep consistency between test sessions which makes for easier later analysis. It also ensures that all usability study research objectives can be accounted for in a testing session as they can all be written as part of the script beforehand [40].

System Usability Scale

The System Usability Scale (SUS) is a method of evaluating the usability of a design or application. It is made up of a 10-item questionnaire along with five response options which range from 'Strongly agree' to 'Strongly disagree'. SUS was originally created by John Brooke in 1986 and it provides a quick method to perform usability testing on a product or application [41].

The 10 questions uses in the SUS questionnaire are:

1. I think that I would like to use this [project] frequently.
2. I found the [project] unnecessarily complex.
3. I thought the [project] was easy to use.
4. I think that I would need the support of a technical person to be able to use this [project].
5. I found the various functions in this [project] were well integrated.
6. I thought there was too much inconsistency in this [project].
7. I imagine that most people would learn to use this [project] very quickly.
8. I found the [project] very cumbersome to use.
9. I felt very confident using the [project].
10. I needed to learn a lot of things before I could get going with this [project].

Once responses have been collected, the SUS score can be calculated, this done by giving a numerical value to each answer with 'Strongly disagree' as a 1 up to 'Strongly agree' at 5. To calculate the total score, it is necessary to do the following:

- For each odd-numbered question, subtract 1 from the user's response
- For each even-numbered question, subtract the user response from 5
- Add up the new values for each user and multiply the total by 2.5.

After completing the above steps, a result will be given in range from 0 to 100 with a higher number indicating a higher score in terms of usability [42].

5.5.2 Usability Testing of the Telemedicine Project

Usability testing of the Telemedicine Project was carried out in two phases. The first phase was completed after the development of a first prototype and was carried out using a usability test script with a small sample size. The second

phase was completed after the rollout of the project with a larger sample size via a survey sent to users which consisted of the SUS standard questions translated into Spanish. The details and results of the usability testing phases are detailed in chapter 8.

Chapter 6

Software Requirements

6.1 Functional Requirements

Following the initial requirements elicitation interviews the following functional requirements were written.

6.1.1 Web Application

The requirements for the web application are separated based on whether they apply to the coordinator user and the specialist user.

Coordinator

(FR1) The coordinator shall be able to log in to the application using their email and password

(FR2) The coordinator user shall be able to assign teleconsultations to a specialist user

(FR3) The coordinator user shall be able to register both rural doctors and specialist doctors onto the platform

(FR4) The coordinator user shall be able to view all submitted teleconsultations on the platform

(FR5) The coordinator user can reassign teleconsultations to a different specialist user

(FR6) The coordinator user shall be able to deactivate and reactivate both specialist and rural doctor accounts from the platform

Specialist

(FR7) The specialist user shall be able to log in to the application using their email and password

(FR8) The specialist user shall be able to view teleconsultations assigned to them by a coordinator

(FR9) The specialist user shall be able to write and save a response to the teleconsultations assigned to them

(FR10) The specialist user shall be able to attach a maximum of 2 files to a response

(FR11) The specialist user shall be able to modify any saved response they have written before it is sent to the rural doctor

(FR12) The specialist user shall be able to send the saved response to the rural doctor

(FR13) After a response has been sent, the specialist user shall be able to view chat messages received from the rural doctor related to the response

(FR14) After a response has been sent, the specialist user shall be able to write and send chat messages to the rural doctor

6.1.2 Android Application

The requirements for the Android application only apply to the rural doctor users.

Rural Doctor

(FR11) The rural doctor shall be able to log in to the application using their email and password

(FR12) The rural doctor shall be able to view their previously submitted teleconsultations

(FR13) The rural doctor shall be able to write teleconsultations

(FR14) The rural doctor shall be able to attach a photo taken from the camera to a teleconsultation

(FR15) The rural doctor shall be able to attach a photo taken from local storage to a teleconsultation

(FR16) The rural doctor shall be able to edit a teleconsultation before uploading it to the web application

(FR17) The rural doctor shall be able to delete teleconsultation before uploading it to the web application

(FR18) The rural doctor shall be able to upload teleconsultations to the web application

(FR19) The rural doctor shall be able to synchronise with the server to download responses

(**FR20)** Once a response has been received, the rural doctor shall be able to write and send messages to the specialist assigned to the teleconsultation

(**FR21)** Once a response has been received, the rural doctor shall be able to receive and read messages sent from the specialist assigned to the teleconsultation

6.2 User Stories

The agile software life-cycle methodology suggests writing user stories in order to bring a human factor to the requirements of a software project. User stories help represent the stakeholders of the project and help explain why a user wants a particular functionality.

In the telemedicine project, there are three different user types: rural doctors, specialist doctors, and coordinators.

6.2.1 Coordinator

The coordinator is used to manage interactions between the other two types of users, rural and specialist. The coordinator will be responsible for registering and deactivating the other user accounts. Coordinators also have the ability to assign teleconsultations to a relevant specialist manually.

- User account registration
- User account deactivation
- Assigning teleconsultations

6.2.2 Specialist doctor

The specialist doctor user receives the consultations relevant to their specialty submitted by the rural doctors and can then provide a response.

- Respond to teleconsultations
- View the list of submitted teleconsultations
- View or modify a specific teleconsultation

6.2.3 Rural doctor

The rural doctor user can create new teleconsultations to be stored locally in the app and subsequently upload said teleconsultations to the web platform for specialist feedback. Rural doctors can then synchronise with the web app in order to download and view the specialist response from the app.

6.3 Stories for the coordinator user

The coordinator doctor should have the ability to carry out the following actions in the web application:

I want to create users for the rural and specialist doctors

- Go to the homepage of the web application and click on the log in button and login with the coordinator details
- On the home page, select the 'Manage Users' button
- On the Manage Users page, select the 'Register new user' button
- Enter the name, email address and password for the new user and select which role (rural or specialist) from the dropdown menu
- If you selected a specialist, select their speciality from the dropdown menu that appears
- Click the register button

I want to see all the submitted teleconsultations

- Go to the homepage of the web application and click on the log in button and login with the coordinator details
- On the home page, select the 'View teleconsultations' button
- Upon opening the teleconsultations page, all submitted teleconsultations will be displayed along with their status (pending assignment or assigned), the required specialty and, if assigned, the specialist to whom it has been assigned.

I want to assign a teleconsultation to a specialist

- Go to the homepage of the web application and click on the log in button and login with the coordinator details
- On the home page, select the 'View teleconsultations' button
- The teleconsultations page displays the list of submitted teleconsultations (and their status), among which are those pending assignment
- Next to the teleconsultaion you want to assign, click the 'Assign to specialist' button
- On the assign specialist page, use the dropdown menu select the specialist doctor who will be in charge of responding to that query.
- Click the 'Assign' button

6.4 Stories of the specialist doctor user

The specialist doctor should have the ability to carry out the following actions in the web application:

I want to see the teleconsultations that I have been assigned

- Go to the homepage of the web application and click on the log in button and log in with the specialist doctor user details
- On the home page, select the 'View teleconsultations' button
- On the teleconsultations page, the list of teleconsultations that have been assigned will be displayed, whether they have been answered or not, along with the status of the consultation (attended or not) and the name of the rural doctor who submitted it.

I want to write and save a response to an assigned teleconsultation

- Go to the homepage of the web application and click on the log in button and log in with the specialist doctor user details.
- On the home page, select the 'View teleconsultations' button
- From the list of teleconsultations, select the one you want to answer
- Check the teleconsultation details and press the respond button
- Fill in the response fields and press the 'Save Response' button.

I want to see and modify a response to a teleconsultation

- Go to the homepage of the web application and click on the log in button and log in with the specialist doctor user details.
- On the home page, select the 'View teleconsultations' button
- From the list of teleconsultations, select the one for which you want to see the response.
- Once the teleconsultation has been viewed, select the 'See response' button.
- Select the fields you want to modify in the response and click on 'Save response'.

I want to send a saved response to a teleconsultation

- Go to the homepage of the web application and click on the log in button and log in with the specialist doctor user details.
- On the home page, select the 'View teleconsultations' button
- From the list of teleconsultations, select the one for which you want to see the response.
- Once the teleconsultation has been viewed, select the 'Send response' button.

I want to view the chat for my assigned teleconsultation

- Go to the homepage of the web application and click on the log in button and log in with the specialist doctor user details.
- On the home page, select the 'View teleconsultations' button
- From the list of teleconsultations, select the one for which you want to see the chat.
- Once the teleconsultation has been viewed, select the 'View chat' button.

I want to send a message in the chat for my assigned teleconsultation

- Go to the homepage of the web application and click on the log in button and log in with the specialist doctor user details.
- On the home page, select the 'View teleconsultations' button
- From the list of teleconsultations, select the one for which you want to see the chat.
- Once the teleconsultation has been viewed, select the 'View chat' button.
- Once the chat page is displayed, type in the desired message and select the 'Send' button.

6.5 Stories of the rural doctor user

The rural doctor should have the ability to carry out the following actions using the Android application:

I want to record the details of a teleconsultation

- Open the Android application and log in with the rural doctor user details
- On the home page, touch the floating '+' button on the bottom right of the screen
- Fill in the relevant fields with the patient details, attach any relevant files or photos and touch the save button

I want to view the details of a saved teleconsultation

- Open the Android application and log in with the rural doctor user details
- On the home page, find the teleconsultation which you would like to view and touch the title text
- The first few fields of the teleconsultation will be displayed, touch and swipe to the left and right to see more of the saved fields

I want to modify the details of a saved teleconsultation

- Open the Android application and log in with the rural doctor user details
- On the home page, find the teleconsultation which you would like to modify and touch the title text
- The teleconsultation details will be displayed, touch the floating modify button on the bottom right of the screen.
- Modify the relevant fields with the new details, touch the save button

I want to delete a saved teleconsultation

- Open the Android application and log in with the rural doctor user details
- On the home page, find the teleconsultation which you would like to modify and touch the trash can icon

I want to upload my teleconsultations to the web application

- Open the Android application and log in with the rural doctor user details
- On the home page, locate the teleconsultation that you want to upload to the web application
- Touch the cloud icon to upload the teleconsultation to the web app.

I want to download and view the specialist response to my teleconsultation

- Open the Android application and log in with the rural doctor user details
- On the home page, touch and drag your finger down on the list of teleconsultations to trigger the app to synchronise with the web app.
- After synchronising, the show response button will no longer be greyed out. Touch on the response button.
- The response details will be displayed, navigate through each sections using the tabs at the top of the screen.

I want to view the chat for my teleconsultation

- Open the Android application and log in with the rural doctor user details
- On the home page, find the teleconsultation for which you would like to view the chat and touch the chat button

I want to send a message in the chat for my teleconsultation

- Open the Android application and log in with the rural doctor user details
- On the home page, find the teleconsultation for which you would like to view the chat and touch the chat button
- The chat page will be displayed, at the bottom of the screen touch the input text box and type your message
- When the message is complete touch the send button

Chapter 7

Development

7.1 Methodology

In order to follow best practice in the development of the applications, the following methodologies were adhered to during development:

- To keep track of what progress was being made on the project as well as gather feedback, a regular weekly meeting was scheduled and conducted using the video calling platform *Zoom*.
- Project tasks and their status was tracked using *Trello*. *Trello* helps with the management of tasks using a card system where cards indicate the status of an individual task. The column that a card is placed in indicates the status of the associated task (e.g in progress, ready for testing). *Trello* is based on the Agile methodology which uses the iterative approach to project management which breaks tasks down into small, but consumable, increments.
- Source control was managed using *Git* and *GitLab* which allowed for the ability to keep track of changes through development and incrementally add features or bug fixes to the codebase. The Gitflow methodology was used to maintain a clear separation between development work and work that was to be ready for the main branch. The Gitflow methodology suggests that alongside the main branch, a develop branch is created on the repository which is used exclusively for development work such as feature additions or fixes.

7.2 Technology

7.2.1 Software Architecture

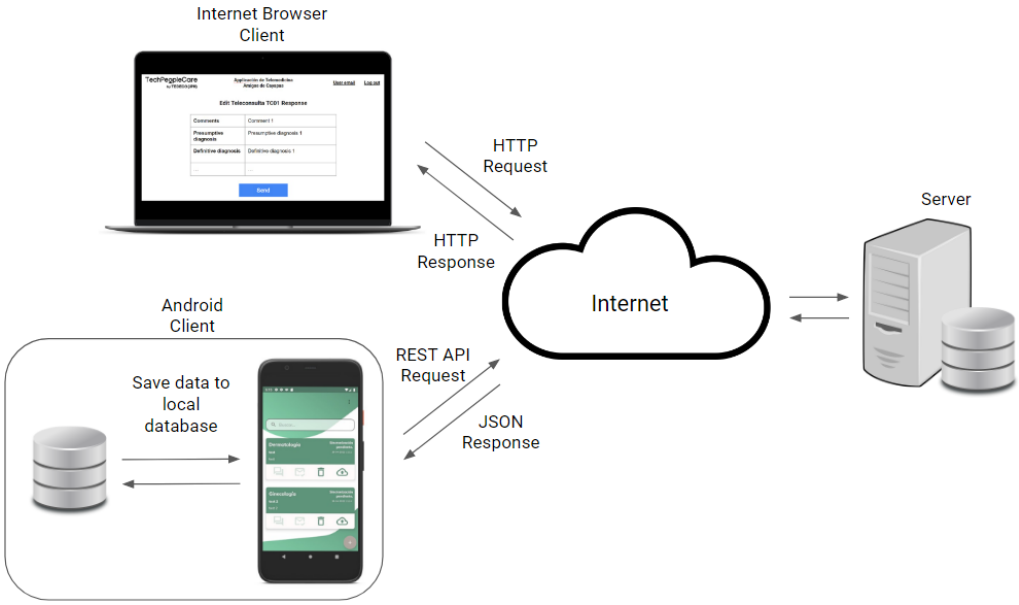


Figure 7.1: Client-server Architecture

The chosen architecture of the web application is a centralized client/server model, the clients will have access to the server via the internet using a web browser from their chosen device. The Android application stores data in a local database stored on the mobile device, this allows for the recording of teleconsultations when the user does not have access to the internet.

7.2.2 Web application

The web application was developed in the Elixir programming language and the Phoenix framework. The choice was made to use Elixir and Phoenix as they are well suited to creating scalable applications, which would mean that the project could be expanded to support more telemedicine projects with more participants.

Phoenix uses a server-side model-view-controller (MVC) pattern which divides the program into three elements: the model which typically represents the database, the view which in this case would be the HTML templates displayed to the client, and the controller which handles client inputs and interacts with the view and model elements.

A PostgreSQL database was used for the web application, the Ecto database toolkit was used to interact with the database from the Phoenix application. Ecto is an official Elixir project providing a database wrapper and integrated query language, it makes interacting with the database simple through its use of secure and composable queries and schemas to map external data to Elixir structs.

The design of the front-end was created using the Phoenix framework views and templates and styling was implemented using Twitter's Bootstrap framework as this allowed for easy mobile support for the web application.

The hosting of the application was handled by the TEDECO web servers using Docker containers. The use of Docker and the Docker Compose tool allowed for building new version releases directly from the GitLab repository which lead to a more streamlined release process. TEDECO also provided the SMTP server which was used to send notification emails to users registered on the platform.

User authentication for the web application was handled by Phoenix's pre-built authentication system phx_gen_auth which follows both security and Elixir best practices. User authentication for Android users was handled by the Guardian token-based authentication library in combination with an API endpoint.

7.2.3 Android application

A large amount of development had been completed on the Android application before starting development, this development work was completed using the Kotlin programming language. The local database was handled by the ObjectBox library, which is a NoSQL database solution designed for mobile devices. The presentation layer was handled by Android Studio's XML layouts which allowed for quick and easy development of UI elements.

Connection to the API was handled using the Retrofit HTTP client library, which allowed for easy parsing from JSON objects to Kotlin data objects and vice versa.

7.3 Web Application Implementation

7.3.1 Presentation

The presentation layer of the web application was handled by Phoenix views and templates which are responsible for rendering the response to the client. Phoenix templates use the *.heex* file format, which stands for HTML+EEx, *heex* files allow for the combination of written HTML code alongside Elixir expressions.

The views available to the client differ based on the user role, likewise some views displayed different information depending on the role of the user. If a user is not logged in and tries to access a restricted page, they are redirected to the login page and an error message is shown telling the user to log in. If a user is logged in but does not have the correct role to view a particular page, they are redirected to the main page and an error message is shown telling the user the page is restricted.

General

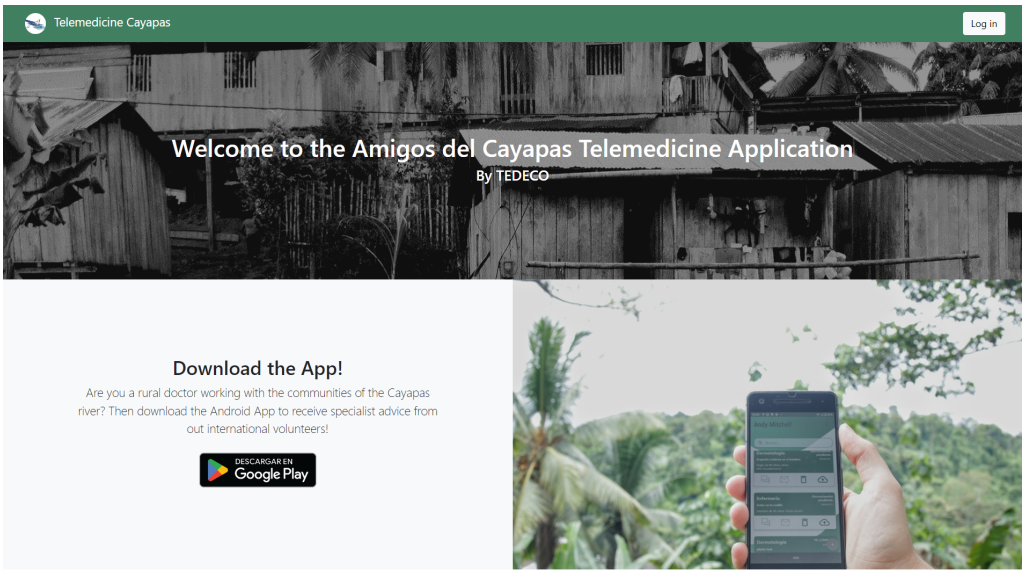


Figure 7.2: Telemedicine Web Application - Home Page

Figure 7.2 shows the home page of the web application. This page is available to the public and provides general information about the telemedicine platform as well as a link to the Google Play Store where the Android application can be downloaded.

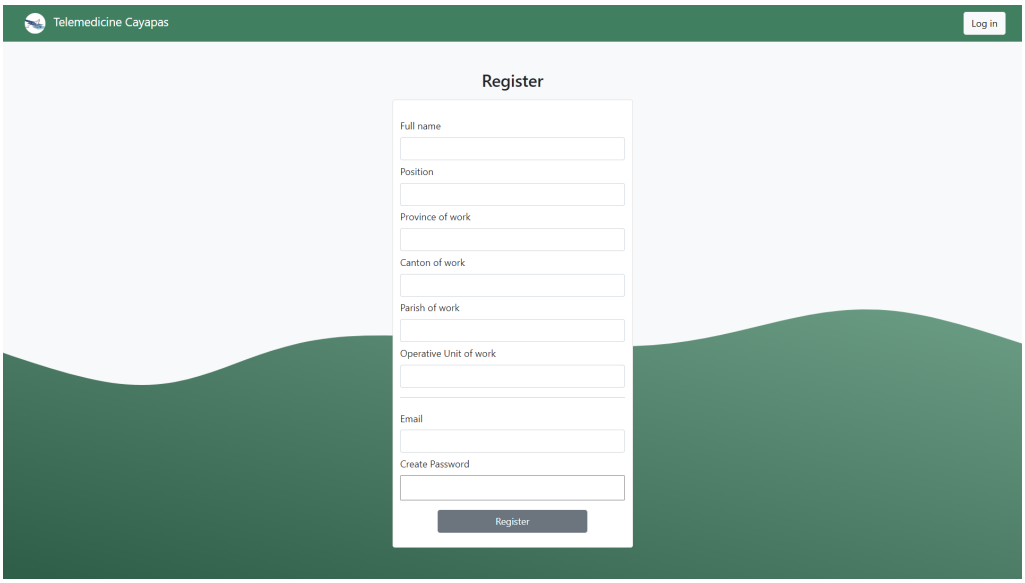


Figure 7.3: Telemedicine Web Application - User Registration Page

Figure 7.3 shows the user registration page. This page is available to the public, however only rural doctors can register their own accounts, it is not

possible to create a specialist or coordinator account using the publicly available registration page. After creating an account, a message is displayed to the user informing them that their account needs to be approved by the coordinator before they can log in.

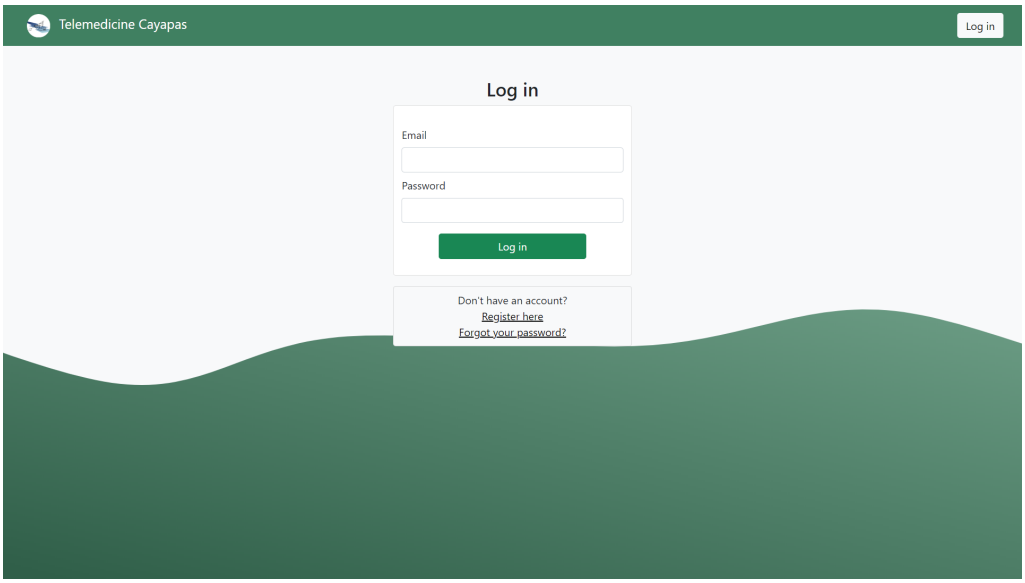


Figure 7.4: Telemedicine Web Application - User Log In Page

Figure 7.4 shows the user log in page. The log in page is available to the public and allows users to log into their accounts, there are also links to create an account as well as a link for users who have forgotten their password.

Teleconsultations

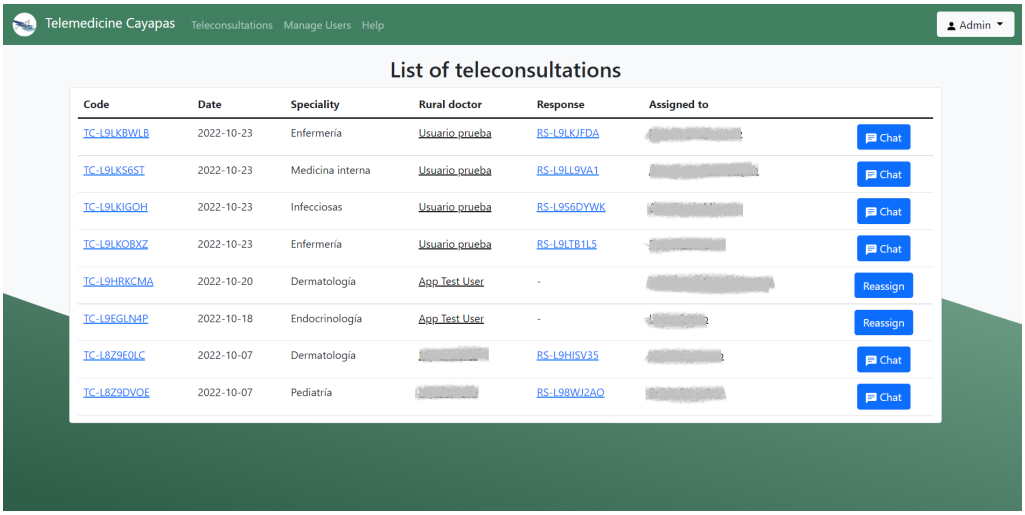


Figure 7.5: Telemedicine Web Application - List of Teleconsultations Page

Figure 7.5 shows the page used to view the list of teleconsultations. This page is only accessible to logged in users and the information and buttons displayed change based on the user that is logged in. In general, this page shows a list of teleconsultations including the code, date, speciality, author, the response (if sent) and the assigned specialist. The different roles will be able to see the following information:

- **Coordinator**

  The coordinator is able to see all teleconsultations submitted to the platform, the options available to the coordinator depend on the status of the teleconsultation. If the teleconsultation is unassigned, an 'Assign' button is shown which links to a page to assign the teleconsultation to a specialist. If the teleconsultation is assigned but a response hasn't been sent yet, a 'Reassign' button is shown which links to a page to reassign the teleconsultation to a different specialist. If a response has been sent, a 'View chat' button is shown allowing the coordinator to view the chat.

- **Specialist**

  The specialist is able to see only the teleconsultations that have been assigned to them by the coordinator, the options available to the specialist depend on the status of the teleconsultation. If no response has been saved or sent, a 'Respond' button is shown which links to the page allowing the specialist to start writing a response to the teleconsultation. If a response has been saved, but not sent, a 'View response' button is shown which links to the view response page where options to send or modify the response are available. If a response has been sent to the teleconsultation, a 'View chat' button is shown allowing the specialist to view and write messages in the chat.

- **Rural doctor**

  The rural doctor is able to see only the teleconsultations they have written, the options available to the rural doctor depend on the status of the teleconsultation. If the teleconsultation has not received a response, there is only the option to view the written teleconsultation. If the teleconsultation has received a response, a 'View response' button is shown which links to a page to view the response from the specialist.

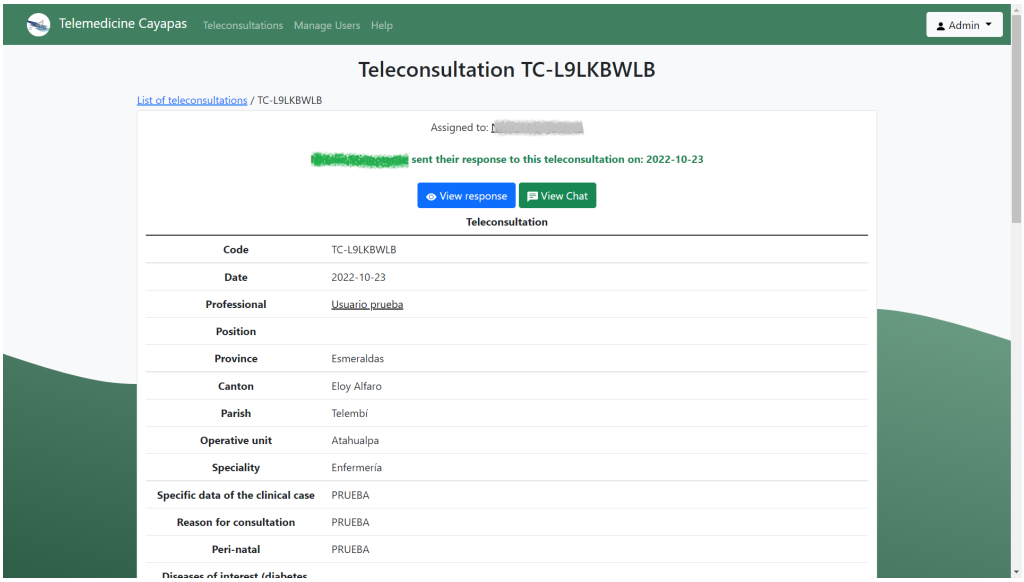


Figure 7.6: Telemedicine Web Application - View Teleconsultation Page

Figure 7.6 shows the page for viewing a specific teleconsultation. This page is only accessible to logged in users and the information and buttons displayed change based on the user that is logged in. This page shows all the information the rural doctor has filled in for the teleconsultation as well as links to the files that are attached to the teleconsultation. The different options available are:

- **Coordinator**

  The information shown to the coordinator depends on the status of the teleconsultation. If the teleconsultation is unassigned, an 'Assign' button is shown which links to a page to assign the teleconsultation to a specialist. If the teleconsultation is assigned but a response hasn't been sent yet, the assigned specialist is shown and a 'Reassign' button is shown which links to a page to reassign the teleconsultation to a different specialist. If a response has been sent, the assigned specialist and the date the response was sent are displayed as well as a 'View chat' button allowing the coordinator to view the chat.

- **Specialist**

  The information shown to the specialist depends on the status of the teleconsultation. If no response has been saved or sent, a 'Respond' button is shown which links to the page allowing the specialist to start writing a response to the teleconsultation. If a response has been saved, but not sent, a 'View response' button is shown which links to the view response page where options to send or modify the response are available. If a response has been sent to the teleconsultation, the date the response was sent is displayed as well as a 'View chat' button allowing the specialist to view and write messages in the chat.

- **Rural doctor**

  The information shown to the rural doctor depends on the status of the teleconsultation. If the teleconsultation has received a response, a 'View response' button is shown which links to a page to view the response from the specialist.

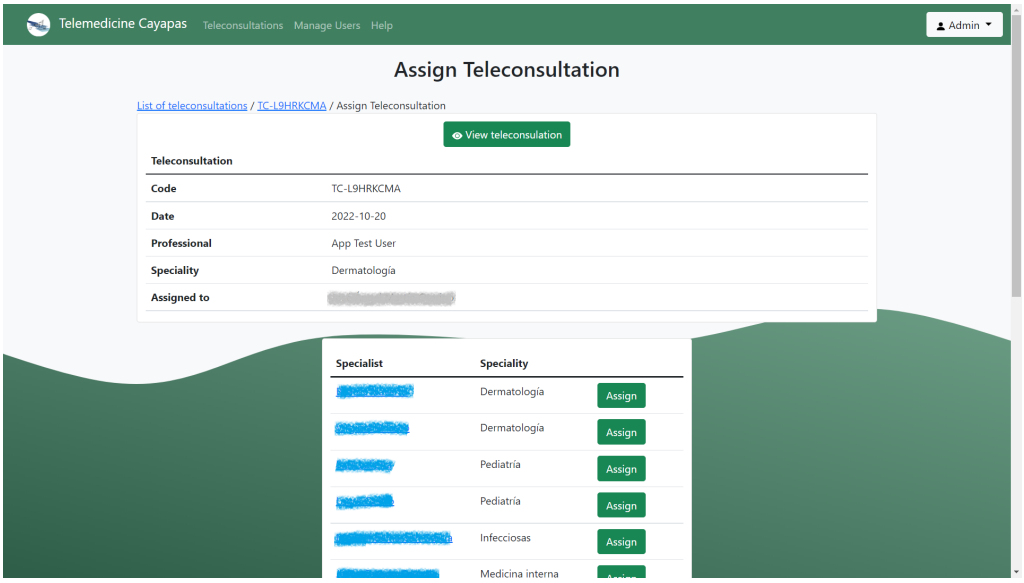


Figure 7.7: Telemedicine Web Application - Assign Teleconsultation Page

Figure 7.7 shows the page for assigning a teleconsultation to a specialist. This page is only available to the coordinator user and is only available for teleconsultations that haven't received a response from a specialist. The page shows basic information about the teleconsultation to assign above a list of specialists to assign the teleconsultation to. The list shows the specialists which correspond to the chosen speciality of the teleconsultation first, although the coordinator can decide to assign a specialist with a different speciality if they desire. This page is also used to reassign a specialist if a teleconsultation has not received a response yet.

Responses

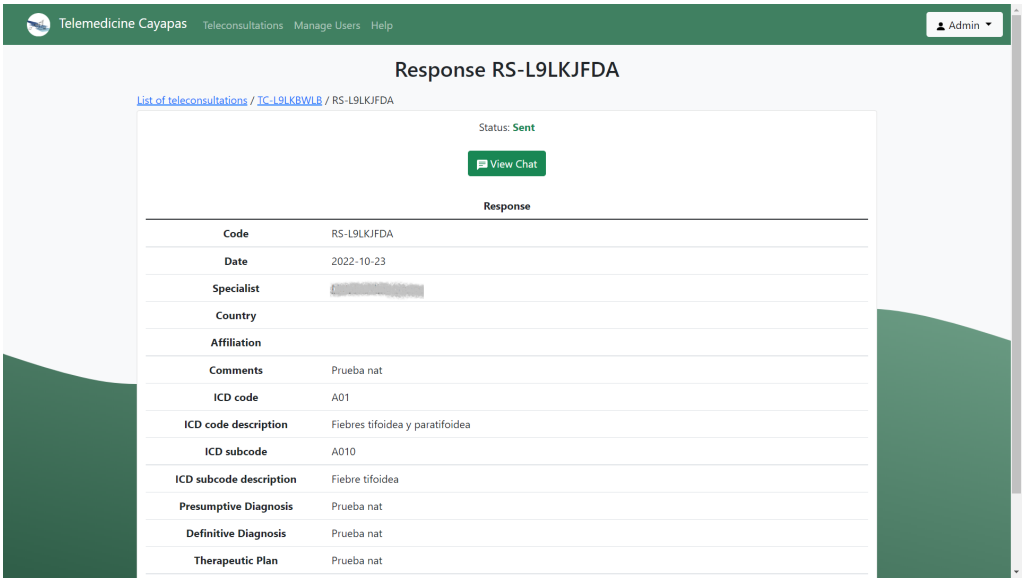


Figure 7.8: Telemedicine Web Application - View Response Page

Figure 7.8 shows the page to view a specialist response. This page is only accessible to logged in users and the information and buttons displayed change based on the user that is logged in. This page shows all the information the specialist has filled in for the response as well as links to the files that are attached to the response. The different options available are:

- **Coordinator**

  The information shown to the coordinator depends on the status of the response. If the response is saved but not sent, a 'Reassign' button is shown which links to a page to assign the teleconsultation to a different specialist. If a response has been sent, the assigned specialist and the date the response was sent are displayed as well as a 'View chat' button allowing the coordinator to view the chat.

- **Specialist**

  The information shown to the specialist depends on the status of the teleconsultation. If a response has been saved, but not sent, a 'Modify response' button is shown which links to the modify response page alongside a 'Send response' button which sends the response to the rural doctor. If the response has been sent, the date the response was sent is displayed as well as a 'View chat' button allowing the specialist to view and write messages in the chat.

- **Rural doctor**

  The view response page is only shown to the rural doctor after the response has been sent. There is a 'View chat' button allowing the rural doctor to

view and write messages in the chat.

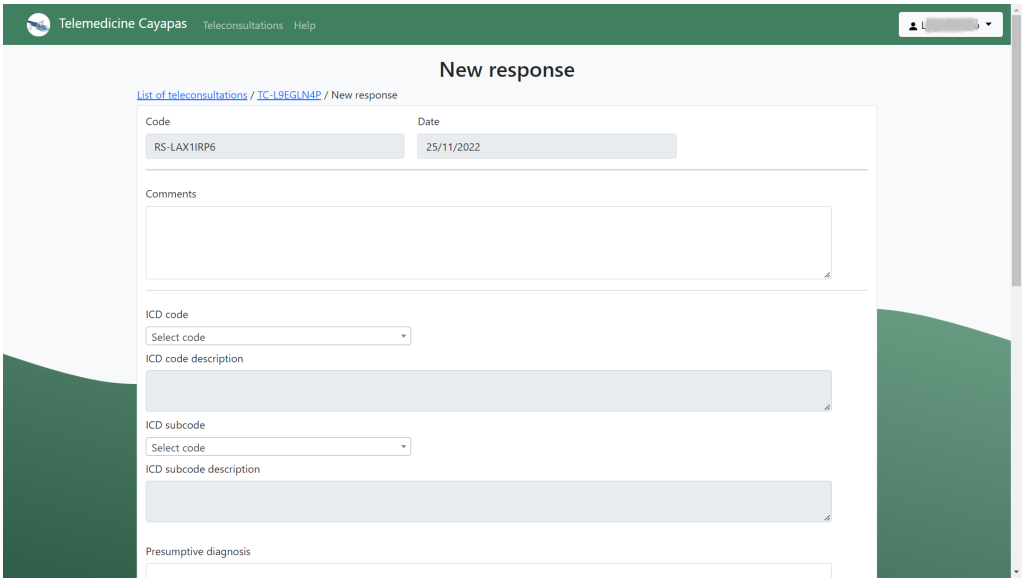


Figure 7.9: Telemedicine Web Application - New Response Page

Figure 7.9 shows the page used to write as well as modify responses. It is only accessible to specialist users and allows specialists to fill in the relevant fields of a teleconsultation response as well as upload and attach support files. Upon completing the response, the specialist has the choice to click the 'Save response' button to save the response to modify later, or a 'Send response' button which sends the response directly to the rural doctor.

Chat

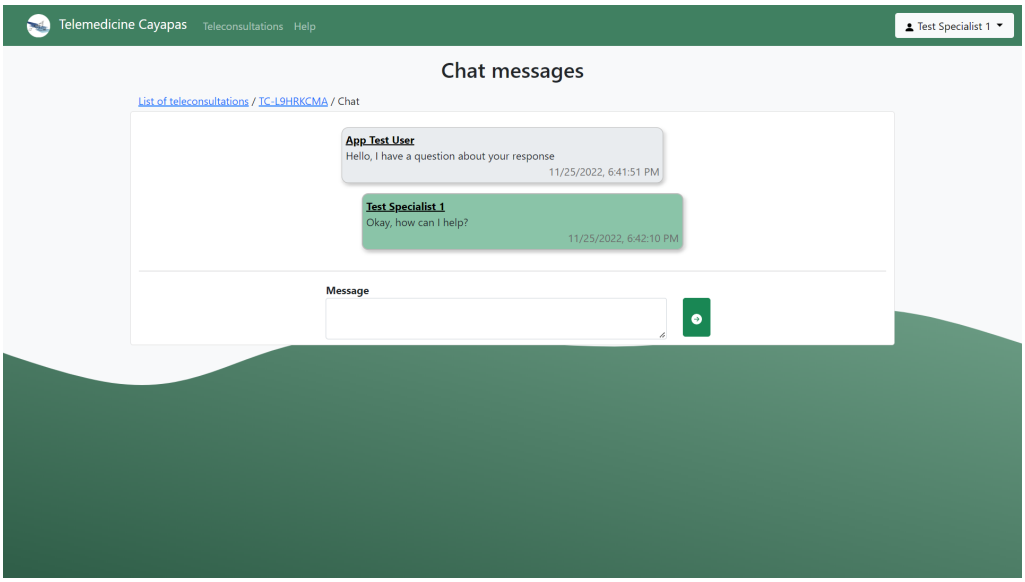


Figure 7.10: Telemedicine Web Application - Chat Page

Figure 7.10 shows the chat page for a particular teleconsultation. Only the rural doctor who wrote the teleconsultation, the assigned specialist and the coordinator can view a particular teleconsultations chat page. The chat page is only available after a response has been sent to a teleconsultation. Messages sent by the logged in user appear in green and other users' messages appear in grey. Each message contains a timestamp of when the message was sent, this is converted to the client's timezone detected using JavaScript.

Manage users

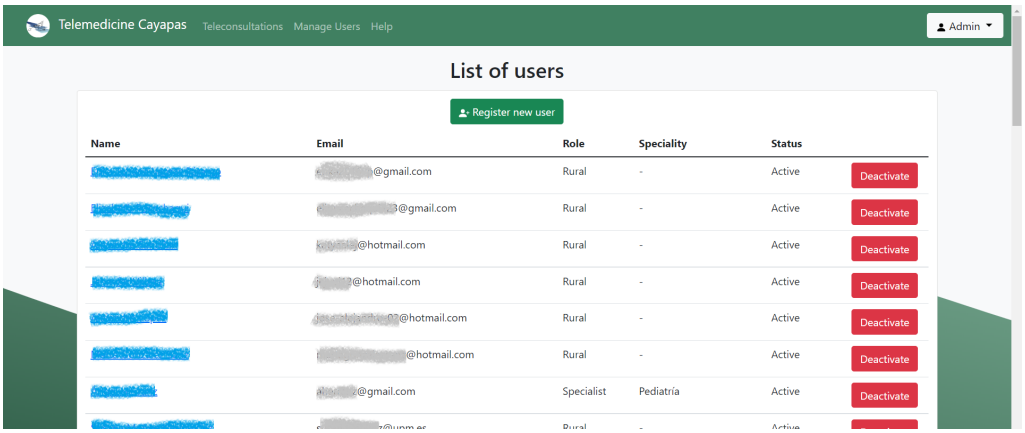


Figure 7.11: Telemedicine Web Application - Manage Users Page

Figure 7.11 shows the page used to manage the registered users on the platform. It is only available to the coordinator user and allows the coordinator to view, active and deactivate accounts registered on the platform. There is also a 'Register new user' which allows the coordinator to create new user accounts.

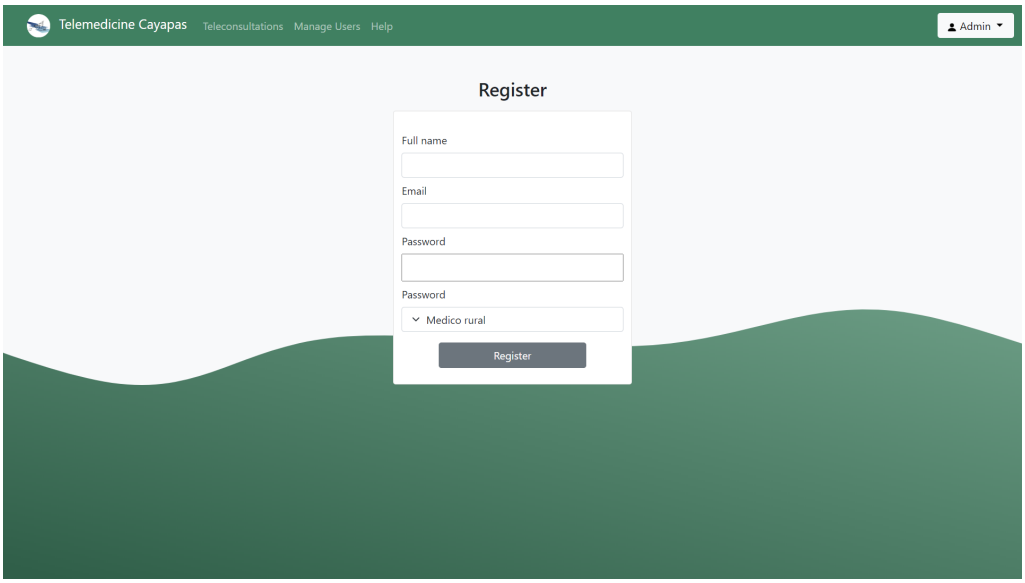


Figure 7.12: Telemedicine Web Application - Coordinator Register New User Page

Figure 7.12 shows the page used by the coordinator to register new users on the platform. It is only available to the coordinator user and allows the coordinator to create either specialist or rural doctor accounts. When creating a specialist a dropdown allows the coordinator to select the speciality of the specialist. Any accounts created by the coordinator are active by default and therefore do not need to be activated after creation.

User settings

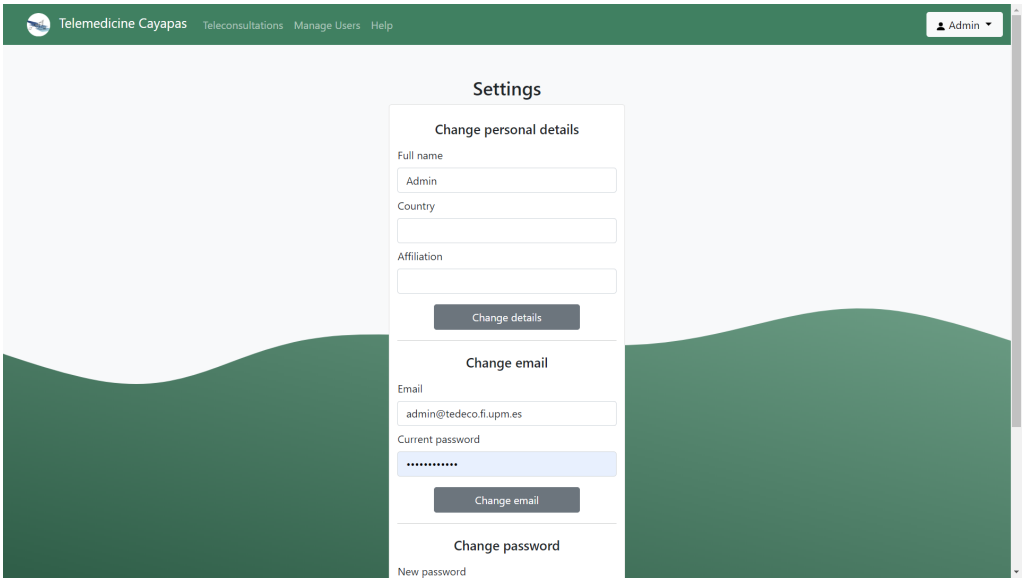


Figure 7.13: Telemedicine Web Application - Configure User Settings Page

Figure 7.13 shows the page to configure user settings. It is only available to logged in users and allows users to change their personal details (e.g. name, position, etc.), email address or password.

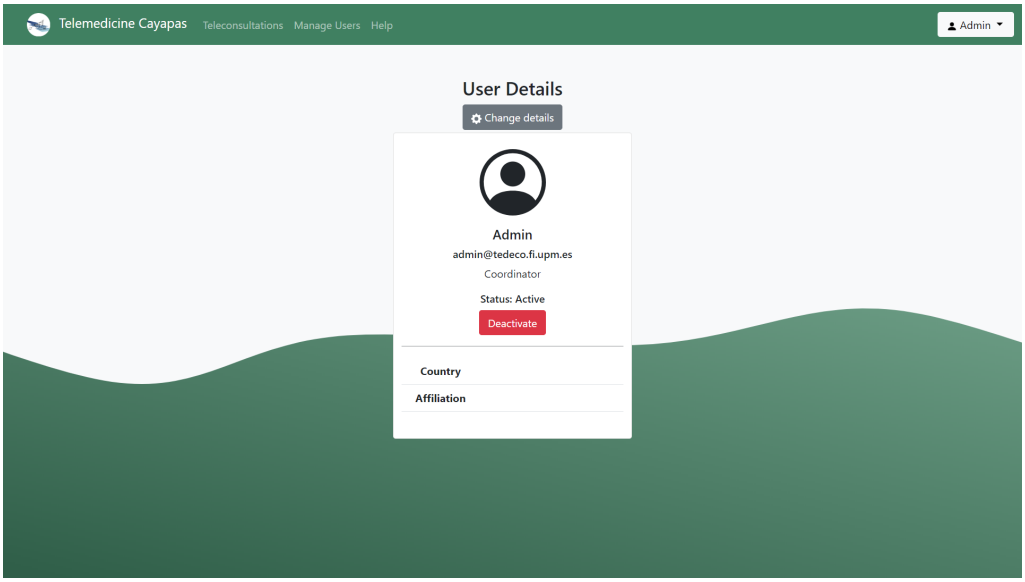


Figure 7.14: Telemedicine Web Application - View User Details Page

Figure 7.14 shows the page to view a specific user's information. It is only available to logged in users, if the user is viewing their own profile, a 'Configure settings' button is shown which links to the configure settings page.

Supported Languages

The application was developed to support both English and Ecuadorian Spanish. The language displayed to the user is decided by a custom plug which determines what language to display by three different methods:

- **URL Parameters**

  If the URL is entered with the termination '?locale=es' or '?locale=en', the website will present all text to the user in Spanish or English respectively.

- **HTTP request header**

  If no cookie or URL parameters have been detected, the application will try to use the Accept-Language HTTP request header from the user in order to set the displayed language.

- **User cookies**

  If a locale is detected from the client from one of the two methods above, a cookie is saved on the client side for a maximum of 10 days storing the language selected. If a user has said cookie, this cookie will determine the language displayed.

If the language cannot be detected based on any of the methods above, the language will be set to the default language which is Spanish.

The translations themselves are provided using the Gettext module for the Phoenix framework. The Gettext module provides an API based on the gettext internationalisation and localisation system commonly used for the development of multilingual programs for Unix-based systems. Translations are stored inside PO (Portable Object) files (file extension .po),the following is an example of a translation stored in a PO file.

```
msgid "View list of teleconsultations"
msgstr "Ver listado de teleconsultas"
```

The msgid indicates the gettext ID that will be used throughout the code of the application, the msgstr is the translation with which the ID will be replaced with if the Spanish language were to be selected. All strings to be displayed to users were translated using the Gettext module, Spanish translations were provided by the native Spanish speakers from the Amigos de Cayapas Association.

7.3.2 Controller

7.3.3 API

The API was designed primary for use by the Android application, it allows users to provide log in details to obtain an JWT authentication token allowing access to user related operations such as sending teleconsultations and downloading specialist responses.

The API has been designed to conform to the OpenAPI specification (previously the Swagger Specification). OpenAPI defines a standard to follow in order to

achieve an language-agnostic interface which is both machine-readable and human-readable. By following the standard both humans and computers should have an understanding of the capabilities of the API service without any other documentation or access to the source code. The available endpoints of the web API are:

- **GET /status**

  Returns the status of the API

- **GET /openai**

  Returns the OpenAI documentation

- **POST /login**

  Accepts a login request in the following JSON format:

  { "email": <user email>, "password": <user password> }

  If valid login details are provided, a JWT token is served to the user

- **GET /specialities**

  Returns a list of the supported specialities for teleconsultations

- **GET /tcs**

  Token authentication required. Returns a list of user's teleconsultations and associated responses and chat messages

- **GET /user**

  Token authentication required. Returns the user details for the authenticated user.

- **GET /tcs/ids**

  Token authentication required. Returns a list of the ids of the user's teleconsultations and associated response and chat message ids

- **GET /tcs/:id**

  Token authentication required. Returns the teleconsultation with the supplied id if the teleconsultation belongs to the user

- **GET /tcs/:id/response**

  Token authentication required. Returns the response and chat messages to the teleconsultation with the supplied id if the teleconsultation belongs to the user

- **GET /tcs/:code/chat**

  Token authentication required. Returns the chat messages to the teleconsultation with the supplied code if the teleconsultation belongs to the user

- **POST /tcs/:code/message**

  Token authentication required. Accepts a chat message in the following JSON format:

```
{
"message": <message content>,
"sent_at": <timestamp of when message sent in UTC format>,
"user_id": <id of user who sent the message>,
}
```

- **POST /tcs**

  Token authentication required. Accepts a teleconsultation in the following JSON format:

```
{
"date": <date of teleconsultation in DD-MM-YYYY format>,
"professional": <name of rural doctor>,
"position": <position of rural doctor>,
"canton": <canton of rural doctor>,
"province": <province of rural doctor>,
"parish": <parish of rural doctor>,
"operative_unit": <operative unit of rural doctor>,
"position": <position of rural doctor>,
"speciality_id": <id of speciality of teleconsultation>,
"specific_data": <contents of 'specific data' field>,
"reason": <contents of 'reason' field>,
"perinatal": <contents of 'perinatal' field>,
"disease_of_interest": <contents of 'disease of interest' field>,
"surgical": <contents of 'surgical' field>,
"obs_gyn": <contents of 'obstetrics and gynecology' field>,
"allergies": <contents of 'allergies' field>,
"medical_history": <contents of 'medical history' field>,
"current_disease": <contents of 'current disease' field>,
"compl_tests": <contents of 'complimentary tests' field>,
"weight": <contents of 'weight' field>,
"height": <contents of 'height' field>,
"heart_rate": <contents of 'heart_rate' field>,
"syst_blood_press": <contents of 'syst_blood_press' field>,
"dias_blood_press": <contents of 'dias_blood_press' field>,
"temperature": <contents of 'temperature' field>,
"respiratory_rate": <contents of 'respiratory rate' field>,
"pain": <contents of 'pain' field>,
"general_aspects": <contents of 'general aspects' field>,
"head_and_neck": <contents of 'head and neck' field>,
"exam_thorax": <contents of 'thorax exam' field>,
"exam_abdominal": <contents of 'abdominal exam' field>,
"lumbo_sacral_reg": <contents of 'lumbo-sacral' field>,
"genitourinary_system": <contents of 'genitourinary system' field>,
```

```
"extremities": <contents of 'extremities' field>,
"exam_musculoskel": <contents of 'musculoskeletal exam' field>,
"exam_skin_nails_hair": <contents of 'skin nails hair exam' field>,
"exam_neuro": <contents of 'neurological exam' field>,
"code3c": <contents of 'code3c' field>,
"code3c_desc": <contents of 'code3c_desc' field>,
"subcode3c": <contents of 'subcode3c' field>,
"subcode3c_desc": <contents of 'subcode3c_desc' field>,
"additional_desc": <contents of 'additional_desc' field>,
"comments": <contents of 'comments' field>,
"file1": {
  "file_name": <file 1 name with extension>,
  "data": <base64 encoded string of file 1>
},
"file2": {
  "file_name": <file 2 name with extension>,
  "data": <base64 encoded string of file 2>
},
}
```

7.3.4 Security

User accounts once registered are stored in the users table in the web application database. A user can log in using their email and password. On the creation of a user account, or when a user changes their password, the password is hashed and stored in the database in the *hashed_password* table. Password hashing and verification is accomplished using the Bcrypt module for Elixir which provides an API for hashing and verifying passwords using the bcrypt hashing function. Research suggests that passwords encrypted using the bcrypt hashing function are resistant to brute force attacks [38].

User authentication for the Android application is achieved using JSON Web Tokens (JWT) provided by the web application API. JWT authentication is handled by the Guardian module for Elixir. The HMAC-SHA256 signing algorithm was used to sign the tokens, the prefix HMAC signifies that the algorithm uses a hash-based message authentication code, the suffix SHA256 indicates the use of the SHA256 hashing function, which is widely used and considered a secure hashing function for web applications.

Mailer

Email is a key part of the web application, emails are send to the user in each of the following situations:

- **Confirm email**

  An email is sent to the user when they create an account in order to confirm their email address

- **Reset password**

  If a user requests a password reset, an email is sent with a link to set a new password

- **Change email**

  If a user requests to change their email, an email is sent with a link to set a new email address

- **New teleconsultation**

  A notification is sent to the coordinator when a new teleconsultation has been submitted to the API

- **New response**

  A notification is sent to the coordinator when a new teleconsultation has been submitted to the API

- **Assigned new teleconsultation**

  When a teleconsultation is assigned to a specialist, an email is send to notify them with a link to view the assigned teleconsultation

- **New chat message**

  When a new chat message is sent, a email will be send to the recipient of the chat message to notify them

- **New registered user**

  When a user creates an account, the coordinator is notified that they will need to activate the account

- **Account activated**

  When the coordinator activates an account, the activated user is notified

7.3.5 Database

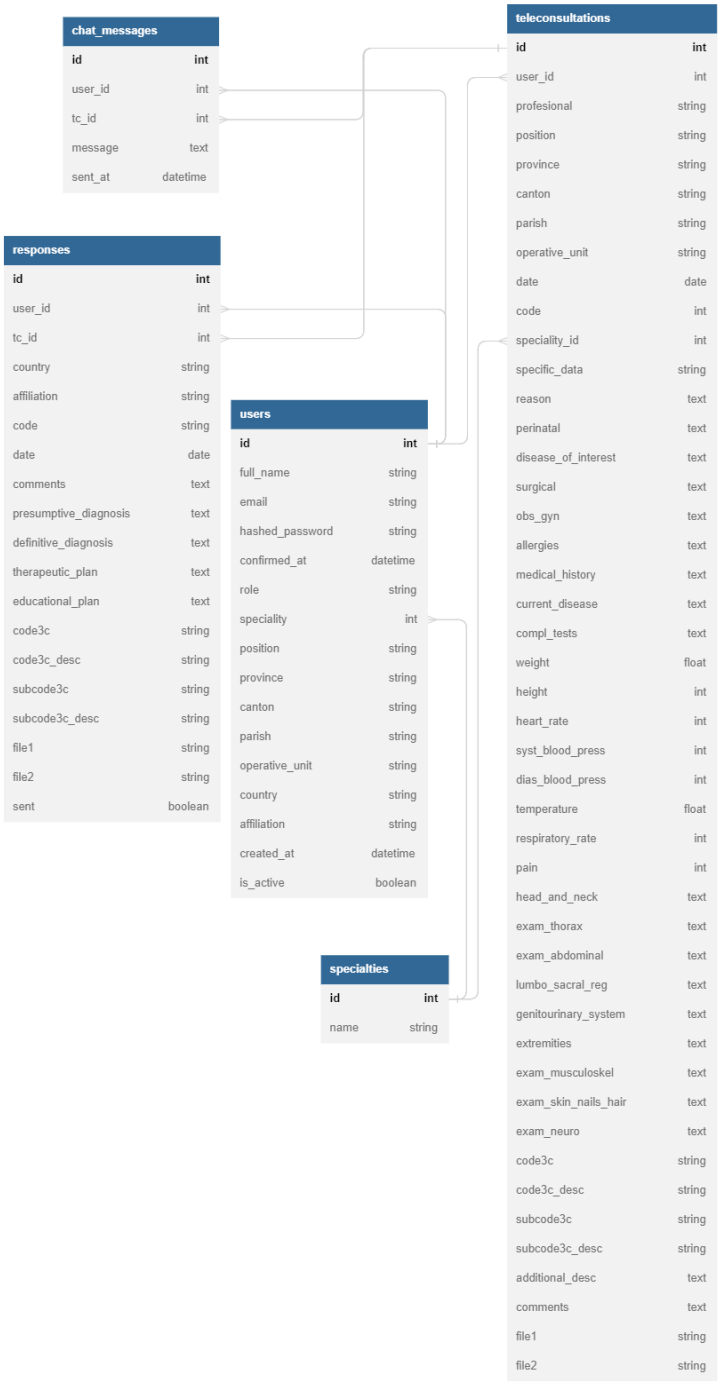


Figure 7.15: Telemedicine Web Application - View User Details Page

Figure 7.15 shows the database schema of the web application. The majority of this schema conforms to the data models extracted from the original Joomla database schema described in section 4.1.1.

7.4 Android Application

7.4.1 Presentation

The majority of the presentation layer of the Android application remains unchanged, however some small changes have been added. The largest of these being the new Chat function described in section 7.4.1.

Log in

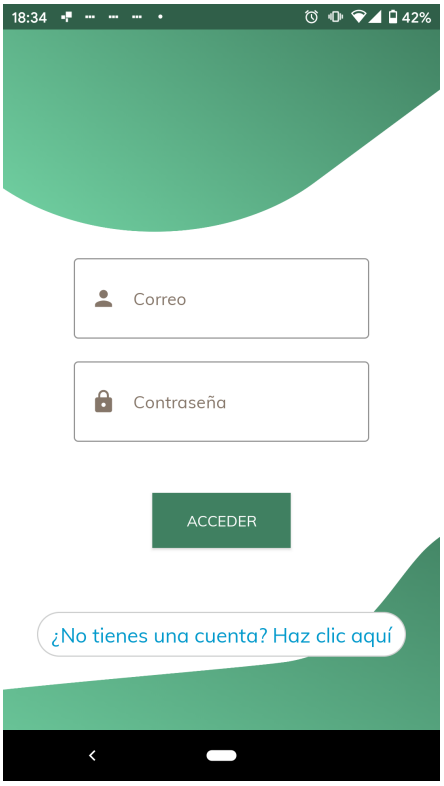


Figure 7.16: Telemedicine Android Application - Log in

Figure 7.16 shows the login page for the application, this remains mostly unchanged. The two main changes are the prompt for the user's email has been changed from 'Usuario' (User in Spanish) to 'Correo' (Email in Spanish). This was changed after early usability tests had participants ask what their username was. The second change to the log in view is the addition of the link to create an account, the blue text at the bottom of the page informs users if they don't have an account they can click the link to register. The link opens the user's web browser and redirects them to the web application's registration page in order to create an account.

Home

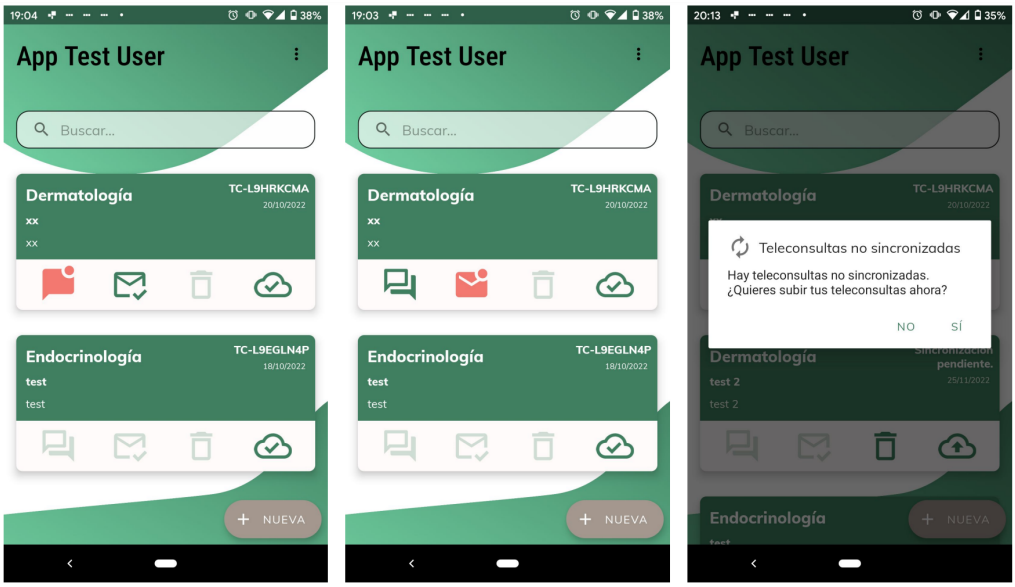


Figure 7.17: Telemedicine Android Application - Home

Figure 7.17 shows the updated home page for the Android application. Most of the UI has remained the same, the major changes are the new teleconsultation action button has now been given the label 'Nueva' (New in Spanish) and the new message and new response indicators. If the nuevaRespuesta or nuevaMensaje boolean properties are set, then the response or chat icon will change to a red icon to indicate the teleconsultation has new information. If a teleconsultation has a new message or response it is automatically shown first in the list of teleconsultations. The final change is a new pop-up which is shown if the user has saved teleconsultations that they haven't synchronised with the server and there is a connection to the internet. The pop-up asks if the user would like to synchronise their saved teleconsultations, if the user responds by touching 'Yes' then the saved teleconsultations are pushed to the server.

View teleconsultation

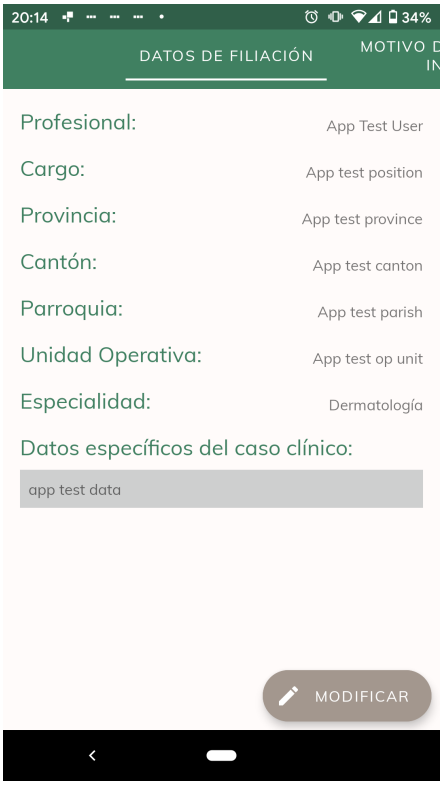


Figure 7.18: Telemedicine Android Application - View teleconsultation

Figure 7.17 shows the view for viewing a user's teleconsultation. This view is mostly the same as before, the only addition is the 'Modificar' button at the bottom left of the display, this allows user's to modify their teleconsultation before uploading it to the server.

View response

Figure 7.19: Telemedicine Android Application - View response

Figure 7.19 shows the view for viewing the response to a teleconsultation. This view is mostly the same as before, with a few changes to fields shown to match the fields used for responses in the web application. The other addition is the ability to save attached files to the local file system. If a response has an attached file, a 'Guardar archivo' (save file in Spanish) is shown, on touching this button, the user's default file management system opens allowing them to to save the file to their local storage.

Chat

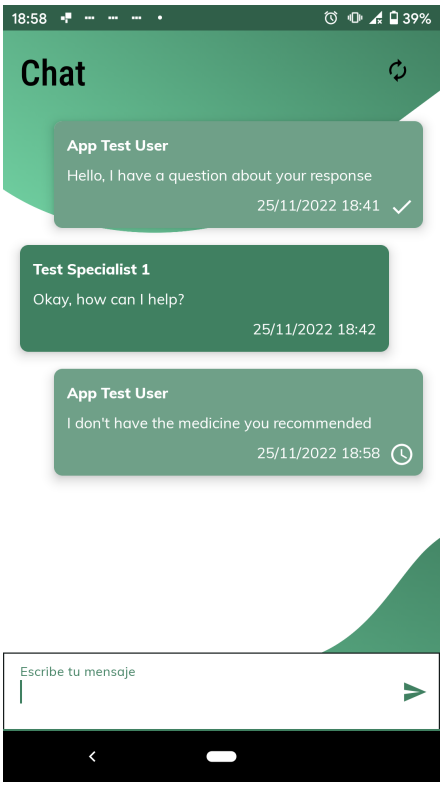


Figure 7.20: Telemedicine Android Application - Chat

Figure 7.20 shows the chat view of the Android application. This view is only available to the user after their teleconsultation has received a response. Upon opening this page, if the user has internet access, a call will be made to the API to download any potential new messages. Messages synchronisation can also be trigger by touching the screen and dragging down, or by touching the synchronise icon at the top right of the screen. User's can write a new message by touching the message box at the bottom of the screen which will bring up the Android keyboard. When the user sends a message, if there is internet the application will send the message to the web platform via an API call, if this is successful a checkmark will be shown below the message as can be seen in the first message in Figure 7.20. If the user does not have a connection to the internet, the message will be saved in the local database and a clock icon will show below the message indicating that it has not been sent to the server.

7.4.2 Controller

Synchronising Teleconsultations

Synchronising teleconsultations can be triggered several different ways:

- User's first log in

- Opening the application after previously having logged in
- User manually touch and drags down whilst looking at the list of teleconsultations
- Background service

The background service uses Androids WorkManager to periodically perform the synchronisation task every 6 hours. This is done by using Android's PeriodicWorkRequests, these Work Requests can be set up to occur indefinitely after an application is opened, they can also be given constraints to determine under what conditions they should be executed (e.g. phone has sufficient battery, WiFi connection, etc.). The PeriodicWorkRequest for teleconsultation synchronisation is only permitted to execute when the user has an internet connection.

In order to synchronise teleconsultations, responses and chat messages, a comparison needs to be made between the data stored locally and the data stored on the server. Before making this comparison, the application first checks whether there are any teleconsultations stored in the local database, if not then an API call is performed to the /api/tcs endpoint to download all the user's teleconsultations, responses and messages. If the local database does contain teleconsultations, then an API call is made to the /api/tcs/ids endpoint which returns the ids of all teleconsultations, responses and chat messages. The returned ids are then compared to the saved ids stored in the local database, if a teleconsultation, response or chat message is missing from the local database then a follow-up API call is made to download the missing teleconsultation, response or chat message. Likewise, if a chat message is saved in the locally database, but hasn't been synchronised with the server, an API call is made to post that chat message to the server.

During the synchronisation process, if a new chat message or a new response is downloaded from the server, the nuevoMensaje or nuevaRespuesta booleans will be set to true for the associated teleconsultation and the teleconsultation will be updated in the database. These booleans are used to update the UI and indicate to the user when a new message or response has been received. If the new message or response is downloaded as the result of a synchronisation triggered by the background service, then a push notification will be sent to the user informing them of the new message or response.

Attached Files

Although a method to attach files was already present in the initial state of the application, early testing showed some issues. No compression or size reduction was performed on attached files and with modern smartphones able to take high-quality photos, the size of photos resulted in slowing loading times when saving a teleconsultation, as well as issues uploading due to the poor internet connections available to rural doctors working in the field. Because of this, any attached photos are resize to have a max width/height of 900px, this resulted in much quicker loading times as well as quicker uploads for teleconsultations.

Attached files are stored in the database as a base64 encoded string, this is also how files are sent to the API.

When downloading teleconsultations responses, attached files are also base64 encoded strings, users are able to save files locally to local storage which is handle by the default local file manager.

7.4.3 Database

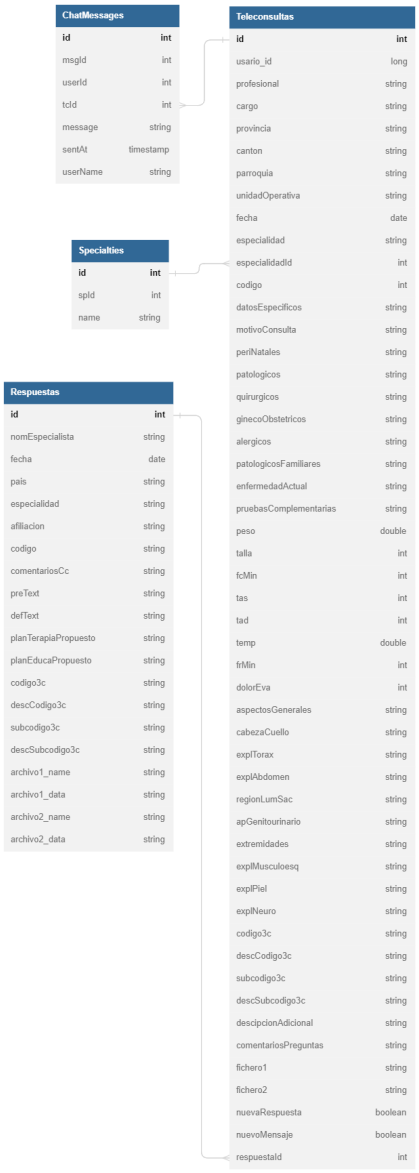


Figure 7.21: Telemedicine Android Application - Database Schema

The database schema as shown in Figure 7.21 shows the changes made to the database. Modifications were made to the database to add a table to store specialities as downloaded by the server, as well as a table to store chat

messages. The table to store responses was restructured to conform with the response format used by the web server. Two new fields were also added to the teleconsultation table, nuevoMensaje and nuevaRespuesta, these are used by the app to indicate that a teleconsultation has a new chat message or new response respectively as well as give a notification to users.

Storage of information related to teleconsultations is handled by the ObjectBox database, user details however and the authentication token however, are stored as key/value pairs using the application's SharedPreferences XML file.

Chapter 8

User Evaluation

User evaluation of the usability of the web and Android applications was completed in two phases. For the first phase, three usability test scripts were written for each of the user types: coordinator, specialist, and rural doctor. The results from the first phase of usability testing were used to improve both applications for a second prototype, a second phase of usability testing with a larger number of participants using the System Usability Scale questionnaire described in section 5.5.1.

8.1 First Usability Testing Phase

Participants were first required to sign a consent form, this consent form asked for their permission to record the session for later analysis for the purpose of improving design and aiding in future development (Appendix A).

As the users of the telemedicine applications fall into one of three different categories, coordinator, specialist, and rural doctor, with each user having a different UI and available actions, a separate usability test script was written for each user.

Each usability test script started with a preamble which was read to the participant. This preamble welcomed the participant and informed them of the length of time the session will run, why the usability testing is taking place, as well as the format of the session (i.e first asking questions, followed by completing a few tasks using the application).

Following this preamble, the participant was told a few things to keep in mind during the session. This informed the participant that the session is intended to test the application, not the participant. The participant was also told to speak candidly as well as to verbalise their thoughts and describe their process.

Several background questions related to the participant and their experience were then asked. These questions were chosen to give an idea of the type of person that will use the application, as well as how they would access the application (e.g type of device, speed of internet access, etc.).

8.1.1 Coordinator

As part of the usability test script, some background questions were asked to the participant, these background questions were chosen to help give a better understanding of the participant's background, previous experience with the telemedicine project, and device setup. On the previous telemedicine platform written in Joomla, there was only one coordinator user created to assign teleconsultations, this coordinator was the single participant chosen for the usability testing of the coordinator user. The background questions included were:

- What is your occupation?
- When you use the telemedicine platform, how do you access the internet?
  - At home? At work? In any other places?
  - Would you use your phone to access the telemedicine platform?
- Do you have a laptop or a desktop PC?
- Do you have an iPad or tablet?
- Do you have broadband?

The above questions were translated into Spanish and asked to the participant after the preamble as shown in the full usability test script (Appendix B).

Following the background questions, the coordinator was asked to complete the following tasks:

The tasks outlined for the coordinator were:

- Create new user for a specialist
- Assign a teleconsultation to a specialist
- Deactivate a user

During each task, several probing questions were asked to the participant in order to obtain more information about the participant's thought process and expectations when using the platform.

Results

Table 8.1 shows the responses to the background questions asked in the usability testing session translated into English. The responses given were taken into account in the development of the second prototype, as the participant reported that they would like to use the platform using their phone and possibly using a tablet, the design decision was made to make the web application responsive using Bootstrap allowing each page to be viewable on different device screens.

Table 8.1: Answers to background questions - Coordinator

Background questions - Coordinator	
Question	**Response**
What is your occupation?	Nurse
When you use the telemedicine platform, how do you access the internet?	At home
Would you use your phone to access the telemedicine platform?	Yes, if possible
Do you have a laptop or a desktop PC?	Laptop
Do you have an iPad or tablet?	Yes, an iPad
Do you have broadband?	Yes

The participant didn't indicate any issues when performing the assigned tasks and only provided positive feedback on the design and usability.

8.1.2 Specialist

As both the specialist and coordinator users were both set up to use the web application exclusively, the background questions asked to the participant of the specialist usability testing were similar to those asked to the participant in the coordinator usability testing. The participant for the specialist usability testing was one of the key members of the Amigos del Cayapas Association who had participated in the previous telemedicine project as a specialist. The questions chosen were therefore aimed to get a better understand of how they used the previous platform as well as their current device set-up.

- What is your occupation?
- When you use the telemedicine platform, how do you access the internet?
  - At home? At work? In any other places?
  - Do you use your phone to access the telemedicine platform?
- Do you have a laptop or a desktop PC?
- Do you have an iPad or tablet?
- Do you have broadband?

The above questions were translated into Spanish and asked to the participant after the preamble as shown in the full usability test script (Appendix C).

Following the background questions, the specialist was asked to complete the following tasks:

- Change user details
- Respond to an assigned teleconsultation
- Respond to a message in the chat

Similarly to the coordinator usability testing session, probing questions were asked during each task, to obtain more information about the participant's thought process and expectations when using the platform.

Results

Table 8.2 shows the responses to the specialist questions asked in the usability testing session translated into English. Again the responses from the participant indicating they would likely use the application from a phone or tablet motivated the design choice to make the web application responsive on multiple screen sizes.

Table 8.2: Answers to background questions - Specialist

Background questions - Specialist	
Question	**Response**
What is your occupation?	Specialist doctor in diseases and infectious diseases
When you use the telemedicine platform, how do you access the internet?	At home
Would you use your phone to access the telemedicine platform?	Probably, yes
Do you have a laptop or a desktop PC?	Laptop
Do you have an iPad or tablet?	Yes, an iPad
Do you have broadband?	Yes

During the completion of the tasks, the participant pointed out a few spelling errors in the Spanish text shown on the pages, which were then corrected for the subsequent prototype. During the task to change user details, the participant first clicked on the link to view their own page from the list of assigned teleconsultations where they looked for a button to modify their details. As there was no such button, the participant required a bit of guidance to find the correct page to update their user details. From this feedback, a 'Modify' button was added to the page to view a profile if the user is viewing their own profile.

The participant also suggested that changes be made to the user details required for the specialist user, in the first prototype these were the same as the rural doctor user and included:

- Province
- Canton
- Parish
- Operative Unit

As these details are more relevant to addresses in Ecuador, whereas the majority of specialists are located in European countries, including things such as Canton and Parish is unlikely to be relevant to the specialists. The suggestion from the participant was to replace these fields with the following:

- Country
- Affiliation

As this information is on for the benefit of the rural doctor to give them information of where their assigned specialist is located, the feedback from the participant suggested that only the country and affiliation would be the most relevant information for the rural doctor. The country and affiliation would give the rural doctor an idea of what health care system they are working in (e.g. a UK based specialist working as a doctor in the National Healthcare Service).

After the above changes were brought to the attention of the members of the TEDECO and Amigos del Cayapas Association, the consensus agreed to change the fields for specialists to the suggestions for the next prototype.

8.1.3 Rural Doctor

The rural doctor usability testing sessions were carried out in person in health centres of the communities of the Cayapas river. As the rural doctor users exclusively use the Android application whilst in the field to interface with the telemedicine platform, the questions were chosen to gain a better understanding of the internet access as well as the devices used by the doctors when working in the field. The background questions asked to the participants of the rural doctor usability testing were:

- What is your occupation?
- Have you used the telemedicine platform before?
  - If not, why not?
  - Did you know it existed?
- If you were to use the telemedicine platform, how would you access the internet?
  - In your room? At the health post? In any other places?
  - Would you use your phone or a different device?
- Do you have an iPad or tablet?
- Do you have an idea of the internet speed you have access to?

The above questions were translated into Spanish and asked to the participant after the preamble as shown in the full usability test script (Appendix D).

The tasks outlined for the rural doctor were:

- Write a teleconsultation

- Read the response to a teleconsultation
- Send a message to a specialist in the chat
- Edit a written teleconsultation
- Delete a teleconsultation

As with the other usability testing sessions, probing questions were asked during each task, to obtain more information about the participant's thought process and expectations when using the platform.

Results

Two participants were chosen for the usability testing, each from a different health post in the Cayapas region. Table 8.4 shows the first participant's responses to the background questions translated into English.

Table 8.3: Answers to background questions - Rural doctor 1

Background questions - Rural doctor 1	
Question	**Response**
What is your occupation?	General doctor
Have you used the telemedicine platform before?	No, heard about it during the last visit from members of the Amigos del Cayapas Association, but I wasn't aware it was ready to use.
If you were to use the telemedicine platform, how would you access the internet?	Probably using my phone, but maybe from my laptop too
Do you have a laptop or a desktop PC?	Laptop
Do you have an iPad or tablet?	No
Do you have an idea of the internet speed you have access to??	At the hotel it is very slow, but it is better at the Zapallo Grande health centre

The first participant didn't indicate any issues when performing the assigned tasks and only provided positive feedback on the design and usability.

Table 8.4: Answers to background questions - Rural doctor 2

Background questions - Rural doctor 2	
Question	**Response**
What is your occupation?	Family doctor
Have you used the telemedicine platform before?	Yes, I have submitted some teleconsultations on the old platform in the past.
If you were to use the telemedicine platform, how would you access the internet?	I used my laptop before, but it would be convenient to use my phone
Do you have a laptop or a desktop PC?	Laptop
Do you have an iPad or tablet?	No
Do you have an idea of the internet speed you have access to?	At Zapallo Grande it is quite fast, but sometimes we lose connection.

The task portion of the usability testing generated some feedback from the second participant. The first prototype showed a floating action button with a '+' icon in order to start a new teleconsultation, the participant did not find this to be obvious enough and recommended that the button be labelled with the word 'new' in Spanish. The participant also had a larger default font size configured on their phone, which resulted in the text on the screens to view a response overflowing off the screen. This meant that the participant was not able to read the full text content of the specialist response and therefore suggested that the screen be scrollable. The participant also commented that it would be useful to be able to highlight and copy parts of the specialist response to the clipboard, which was not possible in the first prototype.

These comments were taken into account in the development of the second prototype, the word 'new' in Spanish was added to the floating action button on the display and all text from the specialist response was configured so that it could be highlighted and copied to the clipboard.

8.2 Second Usability Testing Phase

The second usability testing phase involved sending out a survey to participants who had used the telemedicine platform. This survey was in the format of a Google Forms questionnaire sent to participants via email, to differentiate the results a different questionnaire was used for each of the user types (coordinator, specialist and rural doctor). Links were sent to users registered on the platform via the email address they registered with.

8.2.1 Coordinator

As with the first usability testing phase, only one participant was chosen as the subject for the SUS questionnaire, this being the coordinator for previous the telemedicine platform.

Results

Table 8.5: Answers to SUS questions - Coordinator

SUS - Coordinator					
Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think that I would like to use the application frequently.	1	0	0	0	0
I found the application unnecessarily complex.	0	0	0	0	1
I thought the application was easy to use.	1	0	0	0	0
I think that I would need the support of a technical person to be able to use this application.	0	0	0	0	1
I found the various functions in this application were well integrated.	1	0	0	0	0
I thought there was too much inconsistency in this application.	0	0	0	0	1
I imagine that most people would learn to use this application very quickly.	1	0	0	0	0
I found the application very cumbersome to use.	0	0	0	0	1
I felt very confident using the application.	1	0	0	0	0
I needed to learn a lot of things before I could get going with this application.	0	0	0	0	1

As with the first usability testing phase with the coordinator, feedback was very positive with a calculated SUS score of 100/100. Obviously this is a very small sample size, but as the participant is the sole intended user of web platform when logged in as the coordinator user, this should not be a concern.

8.2.2 Specialist

After the development of the new prototype, a total of 6 different specialists had responded to teleconsultations, these were either real clinical case submitted by rural doctors working in Cayapas, or test teleconsultations submitted by members of the Amigos del Cayapas association. Each of the specialists involved had previous experience with the old telemedicine platform and were therefore familiar with the process of responding to teleconsultations. Each of these 6 specialists was sent a link to the Google Forms questionnaire. A total of4 of these specialists responded to the survey.

Results

Table 8.6: Answers to SUS questions - Specialist

SUS - Specialist					
Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think that I would like to use the application frequently.	4	0	0	0	0
I found the application unnecessarily complex.	0	0	0	2	2
I thought the application was easy to use.	4	0	0	0	0
I think that I would need the support of a technical person to be able to use this application.	0	0	0	1	3
I found the various functions in this application were well integrated.	3	1	0	0	0
I thought there was too much inconsistency in this application.	0	0	0	2	2
I imagine that most people would learn to use this application very quickly.	3	1	0	0	0
I found the application very cumbersome to use.	0	0	0	1	3
I felt very confident using the application.	3	1	0	0	0
I needed to learn a lot of things before I could get going with this application.	0	0	0	1	3

The responses for the specialist questionnaires were mostly positive with an average SUS score of 93.75/100.

8.2.3 Rural Doctor

Following the development of the second prototype, a presentation was given at the hospital supporting the communities of the Cayapas river in Borbon demonstrating the new Android applciation. Healthcare professionals stationed at several of the health posts of the Cayapas river attended this presentation and a total of 26 rural doctors signed up to the platform. During this presentation, the attendees were given an example clinical case from which they were to write a teleconsultation.

Following this presentation, the rural doctors were encouraged to submit teleconsultations with any real cases they came across in their time in the community health posts, and after a period of several weeks, the Google Forms questionnaire was emailed to all registered rural doctors on the platform. However, during these weeks, only one rural doctor submitted a total of two teleconsultations to the platform, similarly, only 5 of the 26 total registered doctors responded to the Google Forms questionnaire.

Results

Table 8.7: Answers to SUS questions - Rural doctor

SUS - Rural doctor					
Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think that I would like to use the application frequently.	4	0	1	0	0
I found the application unnecessarily complex.	1	0	0	2	2
I thought the application was easy to use.	5	0	0	0	0
I think that I would need the support of a technical person to be able to use this application.	0	0	0	1	4
I found the various functions in this application were well integrated.	4	1	0	0	0
I thought there was too much inconsistency in this application.	0	0	1	1	3
I imagine that most people would learn to use this application very quickly.	5	0	0	0	0
I found the application very cumbersome to use.	0	0	0	1	4
I felt very confident using the application.	2	2	0	0	1
I needed to learn a lot of things before I could get going with this application.	0	0	0	0	5

The responses from the rural doctor survey were again mostly positive with an SUS score of 89.5 out of 100. However, the sample size is particularly small with only a 19.23% response rate to the questionnaire. It is also worth noting that only one of the rural doctors completed a teleconsultation with a real patient, which might suggest some aversion to using the platform related to the usability of the platform.

Chapter 9

Conclusions and Future Work

The results of the functional and usability testing suggest that the new telemedicine platform is acceptable and feasible for use by rural doctors working in the communities of the Cayapas river. However, the success of the platform is not only dependent on its technical capabilities, but also on its ability to effectively engage and meet the needs of its users. Adoption and usage was found to be low among the intended users. This lack of uptake may be attributed to a variety of factors, such as a lack of awareness or understanding of the application's benefits, or a lack of trust in the technology.

9.1 Conclusion

The work described in this thesis aimed to develop and evaluate a telemedicine platform to improve the quality of healthcare given to members of the Cayapas communities. Through a combination of functional and usability testing, the technical capabilities and potential of the platform have been validated.

Functional testing demonstrated that the telemedicine platform was technically sound and able to meet the functional requirements effectively. Additionally, usability testing gave insight into the user experience of the platform and identify specific areas for improvement which were then implemented into a second prototype. The results of these tests indicate that the telemedicine platform has the potential to improve the quality of healthcare for many individuals living in the communities of the Cayapas river.

However, it was also found that user adoption and usage was low among the rural doctors who registered with the platform, this could be due to a variety of factors such as familiarity with technology, a lack of trust in the benefits platform, or resistance to change. Despite these challenges, the inclusion of both functional and usability testing in the development and evaluation process has identified the potential benefits the telemedicine platform can provide and has provided sufficient insight to make further recommendations for future work, including conducting further user research and testing, implementing a comprehensive education and outreach strategy, addressing doctor concerns,

and gathering continuous feedback.

9.2 Personal Reflections

On a personal level, I feel I have improved my knowledge of functional programming considerably. All my previous programming projects utilised object-oriented programming, so having the opportunity to work on a web application written exclusively in a functional programming language was an excellent opportunity to improve my skills in this area. I found that designing the appropriate software pattern for synchronising teleconsultations also proved to a unique challenge for me and provided a great opportunity to improve my knowledge of such patterns and how they are used by similar applications.

I gained a great deal from the 2 months I spent living and working on the platform in the different indigenous and Afro-Ecuadorian communities around the Cayapas river, it proved to be both incredibly rewarding and challenging. Many of the communities face social and economic challenges, including poverty, lack of access to basic services and infrastructure, and marginalization from mainstream society. The challenges these communities face had a personal impact on me and gainer a greater understanding of the situation helped identify improvements to be added the development of the platform. The limited access to the internet made development difficult but also motivated me to improve the efficiency of the application so that less data needed to be transferred when synchronising teleconsultations between the Android application and the server.

Overall the experience has been incredibly valuable in both my personal and professional development and I am very grateful to have the opportunity to work on such a project.

9.3 Future Work

Although the telemedicine platform was a technical success, the lack of telelconsultations submitted by the rural doctors shows a lack of adoption of the application by the intended user base, the rural doctors working in the health posts of the Cayapas river. It is important for the future of the Cayapas telemedicine project as well as developers of future telemedicine platforms to conduct further user research and testing to ensure that the platform can bring the desired improvements to the healthcare in remote and austere communities.

Based on the findings of this thesis, the following recommendations can be made for future work in the development and implementation of telemedicine applications:

- Conduct further user research and testing: Further understanding the motivations of the rural doctors and other healthcare professionals working in and around remote communities such as those found around the Cayapas river would help identify potential reasons for the lack of adoption as well as highlight ways in which the platform can be improved.

- Implement an education and outreach strategy: To increase awareness and understanding of a telemedicine platform, an education and outreach strategy can be developed. This can include providing information about the application's benefits and functionality, as well as providing training and support to users.
- Address user concerns and build trust: Many users may be hesitant to use a telemedicine application due to a variety of factors such as concerns about data privacy or lack of awareness of the potential benefits. It is important to address these concerns by setting up methods of direct communication with the rural doctors and other healthcare professionals in the region to address potential concerns and build trust between the association and the healthcare professionals.
- Continuously gather and respond to feedback: It is important to continuously gather and respond to feedback from users in order to identify any issues or areas for improvement. This can be done by conducting regular surveys or by providing an easy-to-use feedback system within the application.
- Consider the environment of the user, the culture and technology literacy of the healthcare professionals it intends to serve to make it more inclusive.

By taking these steps, future telemedicine application developers have the potential to improve the quality of healthcare in these remote and austere environments by creating an application that meets the needs and preferences of the healthcare professionals working in these communities, while also building trust and confidence in the technology.

Bibliography

[1] R. López-Pulles, L. Mora, G. Fernandez, and P. Echanique, "Programa nacional de telemedicina/telesalud – Ecuador," *Latin Am J Telehealth*, vol. 2, pp. 286–301, 01 2010.

[2] L. Murillo and E. Maritza, "Estudio de viabilidad y sostenibilidad técnica, de infraestructura y humano para la implementación de un modelo de atención en telemedicina y telesalud rural en la provincia de zamora chinchipe, de julio a diciembre de 2013," Ph.D. dissertation, Universidad Técnica Particular de Loja, 2015.

[3] L. A. Vasquez-Cevallos, J. Bobokova, P. V. González-Granda, J. M. Iniesta, E. J. Gómez, and M. E. Hernando, "Design and technical validation of a telemedicine service for rural healthcare in Ecuador," *Telemedicine and e-Health*, vol. 24, no. 7, p. 544–551, 2018.

[4] A. Martínez, V. Villarroel, J. Seoane, and F. del Pozo, "A study of a rural telemedicine system in the Amazon region of Peru," *Journal of Telemedicine and Telecare*, vol. 10, no. 4, p. 219–225, 2004.

[5] L. Vasquez Cevallos, "Evaluación del impacto de un servicio de teleconsulta médica en la formación práctica de estudiantes de pregrado en Loja - Ecuador," Ph.D. dissertation, Universidad Politécnica de Madrid, Sep. 2017.

[6] Redacción, "Población del país es joven y mestiza, dice censo del INEC," Sep 2011. [Online]. Available: https://www.eluniverso.com/2011/09/02/1/1356/poblacion-pais-joven-mestiza-dice-censo-inec.html

[7] M. Weisbrot, J. Johnston, and L. Merling, "Decade of reform: Ecuador's macroeconomic policies, institutional changes, and results," Jun 2021. [Online]. Available: https://cepr.net/report/decade-of-reform-ecuador-s-macroeconomic-policies-institutional-changes-and-results/

[8] I. N. de Estadística y Censos, "Anuario de recursos y actividades de salud," 2014. [Online]. Available: https://www.ecuadorencifras.gob.ec/anuario-de-recursos-y-actividades-de-salud/

[9] M. T. Mijares, "Telemedicine in Ecuador: Failure or a learning experience?" *Proceedings. 6th International Workshop on Enterprise Networking and Computing in Healthcare Industry - Healthcom 2004 (IEEE Cat. No.04EX842)*, 2004.

[10] T. Sandor, F. González Bernaldo de Quirós, T. Molina, and F. Plazzotta, "Gestión de información, diálogos e intercambio de conocimientos para acercarnos al acceso universal a la salud," *Conversaciones sobre eSalud*, Jan 2014.

[11] W. H. Organization, *Telemedicine: Opportunities and developments in member states*. World Health Organization, 2011.

[12] S. Garfan, A. Alamoodi, B. Zaidan, M. Al-Zobbi, R. A. Hamid, J. K. Alwan, I. Y. Ahmaro, E. T. Khalid, F. Jumaah, O. Albahri, A. Zaidan, A. Albahri, Z. Al-qaysi, M. Ahmed, M. L. Shuwandy, M. M. Salih, O. Zughoul, K. Mohammed, and F. Momani, "Telehealth utilization during the covid-19 pandemic: A systematic review," *Computers in Biology and Medicine*, vol. 138, p. 104878, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0010482521006727

[13] Telehealth.HHS.gov, "Telehealth and remote patient monitoring," Nov 2022. [Online]. Available: https://telehealth.hhs.gov/providers/preparing-patients-for-telehealth/telehealth-and-remote-patient-monitoring/

[14] L. Bonnardot and R. Rainis, "Store-and-forward telemedicine for doctors working in remote areas," *Journal of Telemedicine and Telecare*, vol. 15, no. 1, p. 1–6, 2009.

[15] D. Dinevski, R. Kelc, and B. Dugonik, "Video communication in telemedicine," *Advances in Telemedicine: Technologies, Enabling Factors and Scenarios*, 2011.

[16] S. Gogia, *Fundamentals of telemedicine and telehealth*. Academic Press, 2020.

[17] V. Saliba, H. Legido-Quigley, R. Hallik, A. Aaviksoo, J. Car, and M. McKee, "Telemedicine across borders: A systematic review of factors that hinder or support implementation," *International Journal of Medical Informatics*, vol. 81, no. 12, pp. 793–809, 2012. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1386505612001542

[18] Y. Pappas, J. Vseteckova, N. Mastellos, G. Greenfield, and G. Randhawa, "Diagnosis and decision-making in telemedicine," *Journal of Patient Experience*, vol. 6, no. 4, pp. 296–304, 2019, pMID: 31853485. [Online]. Available: https://doi.org/10.1177/2374373518803617

[19] F. López Seguí, S. Walsh, O. Solans, C. Adroher Mas, G. Ferraro, A. García-Altés, F. García Cuyàs, L. Salvador Carulla, M. Sagarra Castro, and J. Vidal-Alaball, "Teleconsultation between patients and health care professionals in the Catalan primary care service: Message annotation analysis in a retrospective cross-sectional study," *J Med Internet Res*, vol. 22, no. 9, p. e19149, Sep 2020. [Online]. Available: https://doi.org/10.2196/19149

[20] F. Verhoeven, L. van Gemert-Pijnen, K. Dijkstra, N. Nijland, E. Seydel, and M. Steehouder, "The contribution of teleconsultation

and videoconferencing to diabetes care: A systematic literature review," *J Med Internet Res*, vol. 9, no. 5, p. e37, Dec 2007. [Online]. Available: https://doi.org/10.2196/jmir.9.5.e37

[21] M. de Salud Pública, "Expediente único para la historia clínica," Mar 2007.

[22] C. Miñaca Paul, "Desarrollo de aplicación web de telemedicina para asesoramiento externo de sanitarios locales en zonas aisladas," 2022.

[23] D. Nazarevich, "What is the software development life cycle? - Innowise group," Oct 2022. [Online]. Available: https://innowise-group.com/blog/what-is-sdlc/

[24] G. McLeod and D. Smith, *Managing information technology projects*. Inspired Press, 2001.

[25] K. Petersen, C. Wohlin, and D. Baca, "The waterfall model in large-scale development," *Lecture Notes in Business Information Processing*, p. 386–400, 2009.

[26] C. Larman and V. Basili, "Iterative and incremental developments. a brief history," *Computer*, vol. 36, no. 6, p. 47–56, 2003.

[27] A. Alliance, "What is agile software development?" Dec 2022. [Online]. Available: https://www.agilealliance.org/the-alliance/what-is-agile/

[28] K. E. Wiegers and J. Beatty, *Software requirements*. Microsoft Press, 2015.

[29] W. E. Lewis and G. Veerapillai, *Software testing and continuous quality improvement*. Auerbach publications, 2005.

[30] J. H. Allen, *Software security engineering: A guide for project managers*. Addison-Wesley, 2008.

[31] S. Dalili, D. Wetter, L. Mayo, and OWASP, "Unrestricted file upload," Oct 2020. [Online]. Available: https://owasp.org/www-community/vulnerabilities/Unrestricted_File_Upload

[32] Kaspersky, "Brute force attack: Definition and examples," May 2022. [Online]. Available: https://www.kaspersky.com/resource-center/definitions/brute-force-attack

[33] "Man-in-the-middle attack to the HTTPS protocol," *IEEE Security and Privacy*, vol. 7, no. 1, pp. 78–81, 2009.

[34] U. Berkeley, "How to protect against sql injection attacks," Sep 2022. [Online]. Available: https://security.berkeley.edu/education-awareness/how-protect-against-sql-injection-attacks

[35] Esheridan and OWASP, "Blocking brute force attacks," Jan 2020. [Online]. Available: https://owasp.org/www-community/controls/Blocking_Brute_Force_Attacks

[36] G. Laccetti and G. Schmid, “Brute force attacks on hash functions,” *Journal of Discrete Mathematical Sciences and Cryptography*, vol. 10, no. 3, p. 439–460, 2007.

[37] M. Conti, N. Dragoni, and V. Lesyk, “A survey of man in the middle attacks,” *IEEE Communications Surveys and Tutorials*, vol. 18, no. 3, p. 2027–2051, 2016.

[38] T. P. Batubara, S. Efendi, and E. B. Nababan, “Analysis performance BCRYPT algorithm to improve password security from brute force,” *Journal of Physics: Conference Series*, vol. 1811, no. 1, p. 012129, mar 2021. [Online]. Available: https://doi.org/10.1088/1742-6596/1811/1/012129

[39] U. R. Team, “Usability testing best practices,” Aug 2022. [Online]. Available: https://www.userinterviews.com/blog/usability-testing-best-practices

[40] C. Lenneville, A. Smolinski, L. Evans, A. Lasch, and D. DeSanto, “Writing a website usability testing script,” 2020. [Online]. Available: https://about.gitlab.com/handbook/product/ux/ux-research/writing-usability-testing-script/

[41] J. Brooke, “Sus: A quick and dirty usability scale,” *Usability Eval. Ind.*, vol. 189, 11 1995.

[42] J. Sauro, “Measuring usability with the system usability scale (SUS),” Feb 2011. [Online]. Available: https://measuringu.com/sus/

Appendices

Appendix A - Usability Test Consent Form

TEDECO

Proyecto de Telemedicina de Cayapas

Prueba de Usabilidad - Formulario de Consentimiento

Gracias por participar en nuestra prueba de usabilidad. Estaremos grabando su sesión para para que los miembros de TEDECO que no puedan estar aquí hoy puedan observar su sesión y beneficiarse de sus comentarios, así como analizar a fondo esta sesión después de su finalización.

Por favor, lea la siguiente declaración y firme donde se indica.

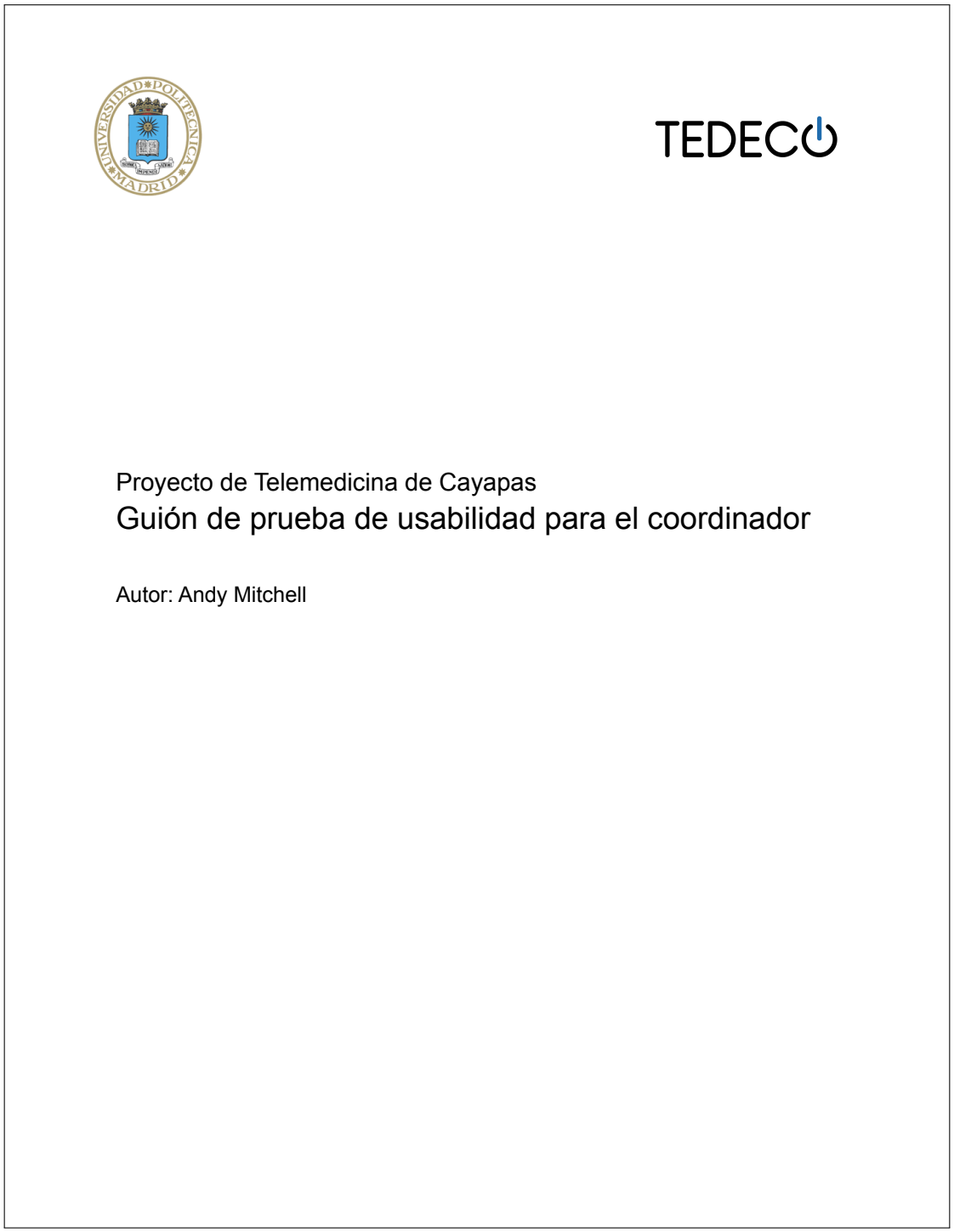
Entiendo que mi sesión de prueba de usabilidad será grabada. Autorizo TEDECO a utilizar esta grabación, con el fin de mejorar los diseños que se están probando.

Firma: _____

Nombre y apellidos: _____

Fecha: _____

Appendix B - Coordinator Usability Test Script



Proyecto de Telemedicina de Cayapas

Guión de prueba de usabilidad para el coordinador

Autor: Andy Mitchell

Prueba Preambulo

Bienvenido

- Gracias por ayudarnos hoy.
- Hemos programado esta sesión para que dure aproximadamente 60 minutos.
- Antes de empezar, le explicaré la configuración y el funcionamiento de la sesión.

Lo que estamos haciendo hoy

- Soy responsable de llevar a cabo una investigación de clientes para el sitio web de telemedicina.
- Intentamos identificar los problemas que podrían solucionarse para que el sitio web sea más fácil de usar.
- Para ello estamos hablando con gente como usted, y basándonos en sus comentarios esperamos
- Identificar las áreas de mejora.

Configuración de la sala

- Le explicaré la configuración
- Le haré preguntas y te hablaré de las pruebas
- Tenemos una cámara y un micrófono para grabar lo que hace. Grabaremos la sesión para tomar notas, pero las imágenes no serán vistas por nadie fuera del equipo
- La sesión se divide en dos partes:
    - En primer lugar, le haremos algunas preguntas sobre su experiencia en el uso de la plataforma en general
    - A continuación, le pediremos que realice algunas tareas en el sitio web de telemedicina y le haremos algunas preguntas sobre la marcha

Algunas cosas a tener en cuenta

- Hay que tener en cuenta algunas cosas que ayudarán a que las pruebas se desarrollen sin problemas...
- En primer lugar, esta sesión se llama prueba de usabilidad. Pero es importante saber que no estamos probando a usted, estamos probando el sitio web. No hay respuestas correctas o incorrectas, no hay preguntas trampa, y no estamos tratando de atraparte de ninguna manera. Si le encuentra con problemas, por favor entiende que no es su culpa, es culpa del software. Y de hecho, cuantos más problemas encuentre, mejor podremos solucionarlos.
- En segundo lugar, sea lo más sincero posible. Si no te gusta algo, o crees que es simplemente que es una tontería, por favor, dilo. No va a herir mis sentimientos - no he estado involucrado en el diseño de ninguna de estas pantallas.
- En tercer lugar, mientras navega por el sitio web, cualquier cosa que se le pase por la cabeza, por favor, verbalícelo. Así, por ejemplo, si está a punto de hacer clic en un botón, diga "voy a hacer clic aquí porque creo que me va a llevar a la siguiente página". O "Estoy buscando la pantalla para crear un usuario". Básicamente, queremos que piense en voz alta; eso nos ayuda a escribir mejores notas. Además, si pudiera abordar las cosas un poco más despacio de lo que normalmente, eso sería muy útil. Si le mueve demasiado rápido por el sitio demasiado rápido, puede que no seamos capaces de tomar notas lo suficientemente rápido. Le recordaré que piensen en voz alta y que vaya más despacio a lo largo de la sesión.
- Por último, no dude en hacer las preguntas que quiera. Es una buena manera de entender sus pensamientos. Pero para que el examen sea lo más realista posible, es posible que no siempre respondo a sus preguntas. Gracias por su comprensión.

¿Tiene alguna pregunta ahora antes de empezar?

Preguntas generales

Antes de que empecemos a utilizar el sitio web, me gustaría hacerle algunas preguntas generales, si le parece bien.

Preguntas personales

- Ocupación
- ¿Cuando usa la web de telemedicina cómo accede a Internet?
    - ¿En casa? ¿En el trabajo? ¿En cualquier otra ubicación que le coincida?
    - ¿Por telefono?
    - ¿Tiene un portátil o un ordenador de sobremesa?
    - ¿Tiene un iPad o tableta?
    - ¿Tiene cable a red?

Tareas

Tarea 1: Crear nuevo usuario para un especialista

Lo que queremos que haga

- Visita https://tedeco.fi.upm.es/cayapas/
- Iniciar sesion con su cuenta de coordinador
- Crear una cuenta de tipo especialista con esta información:
    - Email: specialist@test.com
    - Contraseña: test1
    - Especialidad: Infecciosas
- Por favor muestrame que haria

Home page

- Que busca?
- Que ve?
- Que espera que ver con cada clic?
- Que vas a hacer proximo?

Pagina de gestionar usuarios

- Que ve en esta pagina?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Tarea 2: Asignar una teleconsulta a un especialista

A efectos de la prueba, supondremos lo siguiente:

- Quiere asignar la teleconsulta de Andy Mitchell al nuevo especialista.

Lo que queremos que haga

- Visita https://tedeco.fi.upm.es/cayapas/
- Asignar la teleconsulta de Andy Mitchell al nuevo especialista
- Por favor muestrame que harias

Home page

- Que busca?
- Que ve?
- Que espera que ver con cada clic?
- Que vas a hacer proximo?

Pagina de teleconsultas

- Que ve en esta pagina?
- Que busca?

Pagina de asignación

- Que ve en esta pagina?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Tarea 3: Desactivar un usuario

A efectos de la prueba, supondremos lo siguiente:

- Quiere desactivar el usuario Test Usuario

Lo que queremos que haga

- Visita https://tedeco.fi.upm.es/cayapas/
- Desactivar el usuario de Test Usuario
- Por favor muestrame que harias

Home page

- Que busca?
- Que ve?
- Que espera que ver con cada clic?
- Que vas a hacer proximo?

Pagina de gestionar usuarios

- Que ve en esta pagina?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Appendix C - Specialist Usability Test Script

TEDECO

Proyecto de Telemedicina de Cayapas

Guión de prueba de usabilidad para el especialista

Autor: Andy Mitchell

Prueba Preambulo

Bienvenido

- Gracias por ayudarnos hoy.
- Hemos programado esta sesión para que dure aproximadamente 30 minutos.
- Antes de empezar, le explicaré la configuración y el funcionamiento de la sesión.

Lo que estamos haciendo hoy

- Soy responsable de llevar a cabo una investigación de clientes para el sitio web de telemedicina.
- Intentamos identificar los problemas que podrían solucionarse para que el sitio web sea más fácil de usar.
- Para ello estamos hablando con gente como usted, y basándonos en sus comentarios esperamos
- Identificar las áreas de mejora.

Configuración de la sala

- Le explicaré la configuración
- Le haré preguntas y te hablaré de las pruebas
- Tenemos una cámara y un micrófono para grabar lo que hace. Grabaremos la sesión para tomar notas, pero las imágenes no serán vistas por nadie fuera del equipo
- La sesión se divide en dos partes:
    - En primer lugar, le haremos algunas preguntas sobre su experiencia en el uso de la plataforma en general
    - A continuación, le pediremos que realice algunas tareas en el sitio web de telemedicina y le haremos algunas preguntas sobre la marcha

Algunas cosas a tener en cuenta

- Hay que tener en cuenta algunas cosas que ayudarán a que las pruebas se desarrollen sin problemas...
- En primer lugar, esta sesión se llama prueba de usabilidad. Pero es importante saber que no estamos probando a usted, estamos probando el sitio web. No hay respuestas correctas o incorrectas, no hay preguntas trampa, y no estamos tratando de atraparte de ninguna manera. Si le encuentra con problemas, por favor entiende que no es su culpa, es culpa del software. Y de hecho, cuantos más problemas encuentre, mejor podremos solucionarlos.
- En segundo lugar, sea lo más sincero posible. Si no te gusta algo, o crees que es simplemente que es una tontería, por favor, dilo. No va a herir mis sentimientos - no he estado involucrado en el diseño de ninguna de estas pantallas.
- En tercer lugar, mientras navega por el sitio web, cualquier cosa que se le pase por la cabeza, por favor, verbalícelo. Así, por ejemplo, si está a punto de hacer clic en un botón, diga "voy a hacer clic aquí porque creo que me va a llevar a la siguiente página". O "Estoy buscando la pantalla para crear un usuario". Básicamente, queremos que piense en voz alta; eso nos ayuda a escribir mejores notas. Además, si pudiera abordar las cosas un poco más despacio de lo que normalmente, eso sería muy útil. Si le mueve demasiado rápido por el sitio demasiado rápido, puede que no seamos capaces de tomar notas lo suficientemente rápido. Le recordaré que piensen en voz alta y que vaya más despacio a lo largo de la sesión.
- Por último, no dude en hacer las preguntas que quiera. Es una buena manera de entender sus pensamientos. Pero para que el examen sea lo más realista posible, es posible que no siempre respondo a sus preguntas. Gracias por su comprensión.

¿Tiene alguna pregunta ahora antes de empezar?

Preguntas generales

Antes de que empecemos a utilizar el sitio web, me gustaría hacerle algunas preguntas generales, si le parece bien.

Preguntas personales

- Ocupación
- ¿Cuando usa la web de telemedicina cómo accede a Internet?
    - ¿En casa? ¿En el trabajo? ¿En cualquier otra ubicación que le coincida?
    - ¿Por telefono?
    - ¿Tiene un portátil o un ordenador de sobremesa?
    - ¿Tiene un iPad o tableta?
    - ¿Tiene cable a red?

Tareas

Tarea 1: Actualizar sus datos personales

A efectos de la prueba, supondremos lo siguiente:

- Email: anagarciamingo@gmail.com
- Contraseña: amingo

Lo que queremos que haga

- Visita https://tedeco.fi.upm.es/cayapas/
- Iniciar sesion con su cuenta de especialista
- Actualizar sus datos personales con suyos
- Por favor muestrame que haria

Home page

- Que busca?
- Que ve?
- Que espera que ver con cada clic?
- Que vas a hacer proximo?

Pagina de configuración

- Que ve en esta pagina?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Tarea 2: Responder a una teleconsulta

A efectos de la prueba, supondremos lo siguiente:

- El coordinador le ha asignado una teleconsulta de Andy Mitchell

Lo que queremos que haga

- Visita https://tedeco.fi.upm.es/cayapas/
- Iniciar sesion con su cuenta de especialista
- Encontrar las teleconsultas que estan asignados a usted
- Responder a la teleconsulta de Andy Mitchell
- Por favor muestrame que haria

Home page

- Que busca?
- Que ve?
- Que espera que ver con cada clic?
- Que vas a hacer proximo?

Pagina de teleconsultas

- Que ve en esta pagina?
- Que busca?

Pagina de mostrar teleconsulta

- Que ve en esta pagina?
- Que espera que ver?
- Que busca?

Pagina de escribir respuesta

- Que ve en esta pagina?
- Que espera que ver?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Tarea 3: Responder a un mensaje del chat

A efectos de la prueba, supondremos lo siguiente:

- Ha respondido a una teleconsulta, y el medico rural le ha enviado un mensaje en el chat

Lo que queremos que haga

- Visita https://tedeco.fi.upm.es/cayapas/
- Leer el mensaje de Andy Mitchell
- Responder al mensaje
- Por favor muestrame que haria

Home page

- Que busca?
- Que ve?
- Que espera que ver con cada clic?
- Que vas a hacer proximo?

Pagina de teleconsultas

- Que ve en esta pagina?
- Que busca?

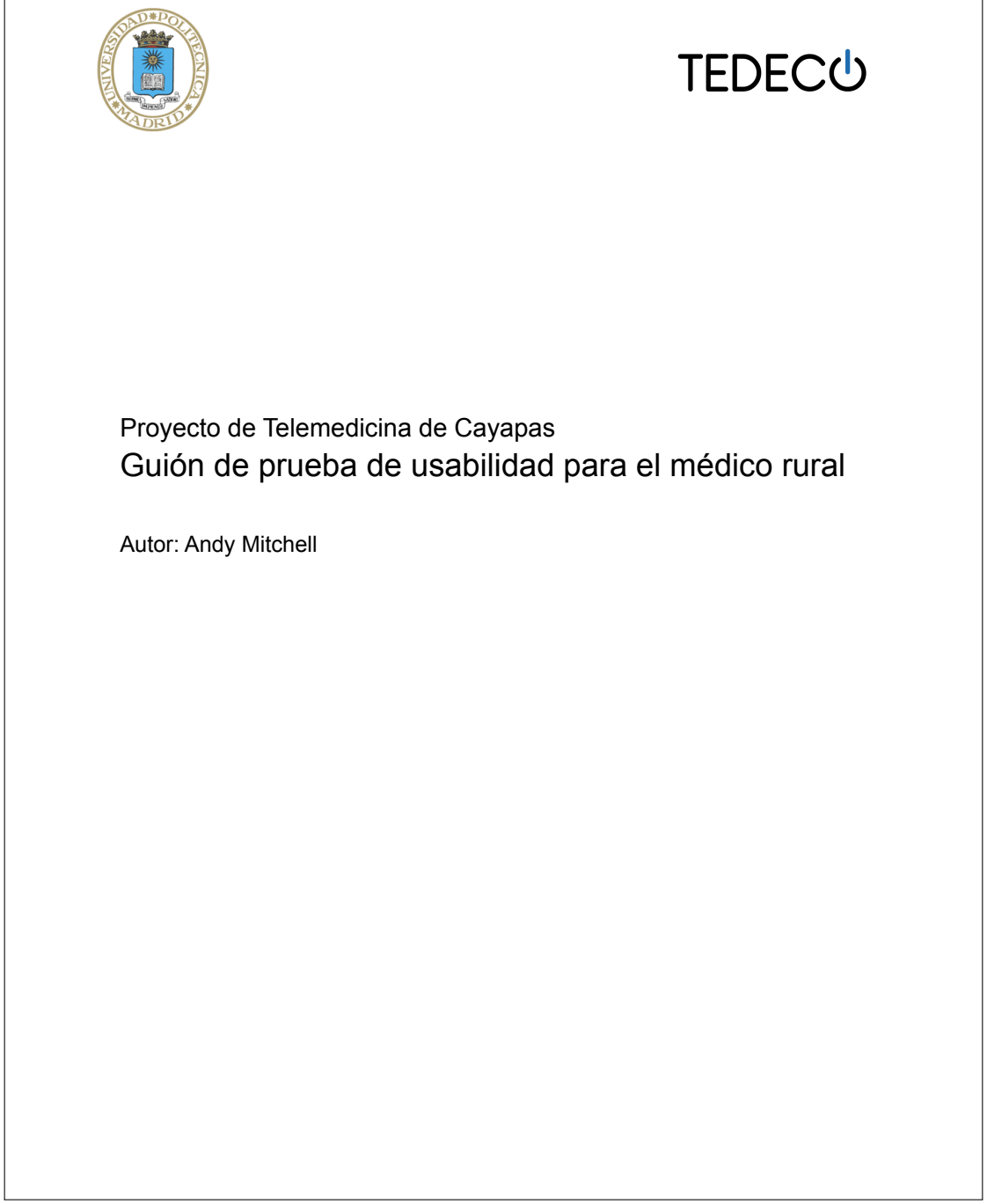
Pagina de chat

- Que ve en esta pagina?
- Que espera que ver?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Appendix D - Rural Doctor Usability Test Script



Proyecto de Telemedicina de Cayapas

Guión de prueba de usabilidad para el médico rural

Autor: Andy Mitchell

Prueba Preambulo

Bienvenido

- Gracias por ayudarnos hoy.
- Hemos programado esta sesión para que dure aproximadamente 30 minutos.
- Antes de empezar, le explicaré la configuración y el funcionamiento de la sesión.

Lo que estamos haciendo hoy

- Soy responsable de llevar a cabo una investigación de clientes para el sitio web de telemedicina.
- Intentamos identificar los problemas que podrían solucionarse para que el sitio web sea más fácil de usar.
- Para ello estamos hablando con gente como usted, y basándonos en sus comentarios esperamos
- Identificar las áreas de mejora.

Configuración de la sala

- Le explicaré la configuración
- Le haré preguntas y te hablaré de las pruebas
- Tenemos una cámara y un micrófono para grabar lo que hace. Grabaremos la sesión para tomar notas, pero las imágenes no serán vistas por nadie fuera del equipo
- La sesión se divide en dos partes:
    - En primer lugar, le haremos algunas preguntas sobre su experiencia en el uso de la plataforma en general
    - A continuación, le pediremos que realice algunas tareas en el sitio web de telemedicina y le haremos algunas preguntas sobre la marcha

Algunas cosas a tener en cuenta

- Hay que tener en cuenta algunas cosas que ayudarán a que las pruebas se desarrollen sin problemas...
- En primer lugar, esta sesión se llama prueba de usabilidad. Pero es importante saber que no estamos probando a usted, estamos probando el sitio web. No hay respuestas correctas o incorrectas, no hay preguntas trampa, y no estamos tratando de atraparte de ninguna manera. Si le encuentra con problemas, por favor entiende que no es su culpa, es culpa del software. Y de hecho, cuantos más problemas encuentre, mejor podremos solucionarlos.
- En segundo lugar, sea lo más sincero posible. Si no te gusta algo, o crees que es simplemente que es una tontería, por favor, dilo. No va a herir mis sentimientos - no he estado involucrado en el diseño de ninguna de estas pantallas.
- En tercer lugar, mientras navega por el sitio web, cualquier cosa que se le pase por la cabeza, por favor, verbalícelo. Así, por ejemplo, si está a punto de hacer clic en un botón, diga "voy a hacer clic aquí porque creo que me va a llevar a la siguiente página". O "Estoy buscando la pantalla para crear un usuario". Básicamente, queremos que piense en voz alta; eso nos ayuda a escribir mejores notas. Además, si pudiera abordar las cosas un poco más despacio de lo que normalmente, eso sería muy útil. Si le mueve demasiado rápido por el sitio demasiado rápido, puede que no seamos capaces de tomar notas lo suficientemente rápido. Le recordaré que piensen en voz alta y que vaya más despacio a lo largo de la sesión.
- Por último, no dude en hacer las preguntas que quiera. Es una buena manera de entender sus pensamientos. Pero para que el examen sea lo más realista posible, es posible que no siempre respondo a sus preguntas. Gracias por su comprensión.

¿Tiene alguna pregunta ahora antes de empezar?

Preguntas generales

Antes de que empecemos a utilizar el sitio web, me gustaría hacerle algunas preguntas generales, si le parece bien.

Preguntas personales

- Ocupación
    - Medico general
- ¿Ha usado la plataforma telemedicina antes?
    - Si no ¿Por qué no? ¿Sabia que existe?
        - No, porque no habia suficiente tiempo para demonstrar la aplicación
- ¿Cuando quiere usar la plataforma telemedicina, cómo accede a Internet?
    - ¿En su habitación? ¿En el puesto de salud? ¿En cualquier otra ubicación que le coincida?
        - Solo en el hotel.
    - ¿Por telefono?
        - Si, y portatil tambien
    - ¿Tiene un portátil o un ordenador de sobremesa?
        - Un portatil, todos tienen uno.
    - ¿Tiene un iPad o tableta?
        - No
    - ¿Tiene una idea de la velocidad de la conexion?

Tareas

Tarea 1: Escribir una teleconsulta

A efectos de la prueba, supondremos lo siguiente:

- Email: teleconsultaZG@cayapapichullakumani.com
- Contraseña: test1
- Esta usted con un paciente con la siguiente características y quiere subir una teleconsulta del caso:
    - Varón de 21 años, etnia Chachi, que acude al Hospital de Borbón procedente de Sabalito.
    - Solicita valoración médica por presentar dos heridas en forma de úlcera cerca del maléolo externo del pie derecho.
    - Refiere 3 meses de evolución.
    - Antecedentes de interés: Diabetes mellitus tipo I.
    - Alergia: amoxicilina.
    - TA: 120/80
    - FC: 80 lpm
    - Sat.02: 99%
    - Peso: 55 Kg
    - Tª: 36,2ºC
    - Talla: 165 cm

Lo que queremos que haga

- Abre la app Telemedicina Cayapas versión 1.0.0-rc1
- Iniciar sesion con su cuenta de medico rural
- Crear una teleconsulta
- Por favor muestrame que haria

Pagina de iniciar sesión

- Que busca?
- Que ve?
- Que espera que ver con cada clic?
- Que vas a hacer proximo?

Pagina de ver teleconsultas

- Que ve en esta pagina?

- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Tarea 2: Leer la repuesta a una teleconsulta

A efectos de la prueba, supondremos lo siguiente:

- La coordinadora le ha asignado su teleconsulta a una especialista
- Ha recibido una repuesta de su teleconsulta

Lo que queremos que haga

- Abre la app Telemedicina Cayapas versión 1.0.0-rc1
- Encontrar la teleconsulta que ha recibido una respuesta
- Leer la respuesta
- Por favor muestrame que haria

Pagina de ver teleconsultas

- Que busca?
- Que ve?
- Que espera que ver con cada clic?
- Que vas a hacer proximo?

Pagina de leer respuesta

- Que ve en esta pagina?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Tarea 3: Enviar un mensaje en el chat

A efectos de la prueba, supondremos lo siguiente:

- Quiere usted que el especialista le explique algo en la respuesta, por eso quiere usted enviarle un mensaje

Lo que queremos que haga

- Abre la app Telemedicina Cayapas versión 1.0.0-rc1
- Enviar un mensaje al especialsita
- Responder al mensaje
- Por favor muestrame que haria

Pagina de ver teleconsultas

- Que ve en esta pagina?
- Que busca?

Pagina de chat

- Que ve en esta pagina?
- Que espera que ver?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Tarea 4: Modificar una teleconsulta

A efectos de la prueba, supondremos lo siguiente:

- Quiere usted modificar una teleconsulta

Lo que queremos que haga

- Abre la app Telemedicina Cayapas versión 1.0.0-rc1
- Crear una teleconsulta para modificar
- Modificar la teleconsulta
- Por favor muestrame que haria

Pagina de ver teleconsultas

- Que ve en esta pagina?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?

Tarea 5: Borrar una teleconsulta

A efectos de la prueba, supondremos lo siguiente:

- Quiere usted borrar la teleconsulta que ha modificado

Lo que queremos que haga

- Abre la app Telemedicina Cayapas versión 1.0.0-rc1
- Borrar la teleconsulta que ha modificado
- Por favor muestrame que haria

Pagina de ver teleconsultas

- Que ve en esta pagina?
- Que busca?

Conclusión

- En general, ¿qué le pareció esa experiencia?
- ¿Hubo algo que le gustó o no le gustó especialmente de ese proceso?
- ¿Había algo que esperaba ver pero no vio?
- ¿Hubo algo que le sorprendiera ver?