Technological Development
Development of a Cardiac Auscultation Virtual Reality App

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Abstract

Cardiac auscultation is a procedure that allows diagnosing a patient's heart condition making use of the stethoscope. Proper examination skills with the stethoscope may result in proper diagnostics and treatment.

Auscultation skills are in decay among health care trainees and even professionals, due to the required extensive training. Current training tools include simulation manikins and diagnostics equipment that is taking a more prominent role in auscultation practice than the training with the stethoscope.

According to the World Health Organization, in 2015 the top two causes of death were ischaemic heart disease and stroke. The availability and low cost of the stethoscope makes it a cost-effective tool in cardiac auscultation skills. Currently, virtual reality consumer-grade devices are allowing the development of affordable virtual experiences that have the potential to complement other forms of training.

In this work a mobile app combines multimedia elements such as heart rhythm sounds and images indicating areas where cardiac exploration should be performed is presented. 3D models with realistic animations of patients with different physical characteristics for the simulation and explanatory text for the diagnosis were used to provide immersion and realism. The system is based on the cardiac auscultation training procedure, making use of game elements in order to engage and motivate users in the learning process.

Resumen

La auscultación cardiaca es un procedimiento que permite diagnosticar la condición del corazón de un paciente haciendo uso de un estetoscopio. Una examinaciOn apropiada con el estetoscopio puede resultar en un adecuado diagnóstico y tratamiento.

Habilidades en auscultación cardiaca están en decaimiento entre practicantes y profesionales de áreas relacionadas al cuidado de la salud debido al extenso tiempo requerido de entrenamiento. Herramientas actuales de entrenamiento incluyen maniquíes de simulación y equipamiento de diagnóstico que está tomando un papel con mayor prominencia en la práctica de auscultación cardiaca que el entrenamiento con el estetoscopio.

De acuerdo con la Organización Mundial de la Salud, en 2015 los dos causantes más grandes de muerte fueron ataques al corazón y enfermedades cerebrovasculares. La disponibilidad y bajo costos del estetoscopio lo hace una herramienta rentable en el entrenamiento en auscultación cardiaca. Actualmente, dispositivos de realidad virtual disponibles para el consumidor común están permitiendo el desarrollo de experiencias virtuales asequibles que tienen el potencial para complementar otras formas de entrenamiento.

En este trabajo se presenta una aplicación móvil que combina elementos multimedia tales como sonidos de ritmos cardiacos e imágenes indicando áreas donde la exploración cardiaca debería ser llevada a cabo. Modelados 3D con animaciones realistas de pacientes con diferentes características físicas para simulación y texto explicativo para el diagnóstico fueron usados para proveer inmersión y realismo. El sistema está basado en el procedimiento de entrenamiento en auscultación cardiaca, haciendo uso de elementos de juego para enganchar y motivar los usuarios en el proceso de aprendizaje.

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1. Introduction

Cardiac auscultation is a routine examination procedure that allows diagnosing the condition of the heart, by employing a stethoscope [1]. Traditionally, the teaching and training of aucultatory skills employed of pre-recorded sounds, patient practice, student-student practice, and illustrations depicting their characteristics [2]. Emphasis on the memorization of all the heart conditions led the learning strategies (practice still used), with limitations regarding the availability of rare conditions due to limited content and patients [3]. Cardiac auscultation competency is achieved through extensive training [1]. However, given the limitations of the traditional training, that in conjunction with training employing modern diagnostic equipment (e.g., dopler or echocardiography) has resulted in the use of newer forms of practice that can provide multiple scenarios in a controlled, safe, and monitored environment where trainees can learn, develop and maintain medical skills [4].

Medical simulation has become the standard for medical training since it allows trainees to be exposed to real-world scenarios with physical or virtual models that allow debriefing and assessing medical skills [5]. However, manikin simulation training face challenges related to their acquisition costs, training, maintenance and availability since only small groups or individual practice can be performed during the practices depending on the skills to be trained [6].

Cardiac auscultation skills development is directly related to learning methods and the access that trainees have to materials that are available. Clinicians who seek to further refine their skills are confronted with a variety of cardiac pre-recordings [7] [8]. The average clinician quickly discovers that it will take years of practice to become skilled in cardiac auscultation [9]. Interpreting heart sounds forms a vital part of the cardiovascular examination, yet accuracy for identifying specific diagnoses has been shown to be low among medical students and trainees [10]. Poor auscultation skills can result in improper diagnoses leaving pathologies aside that can potentially become a health risk.

In this work, we present the development of a cardiac auscultation mobile app that can potentially be used as a complementary training tool.

1.1. Problem

Heart diseases are among the main causes of death worldwide according to the World Health Organization [9]. Early diagnosis and proper treatment can make the difference between life and death. In a medical examination, cardiac auscultation is the main diagnostics procedure employed to diagnose a heart condition. Although, cardiac auscultation is a subjective examination technique due to the sound interpretation made by the physician [11], it is still a cost effective technique relevant to medical examination [8]. Even multimedia developments presenting interactive heart models, animations, videos, and enriched text provide galleries of sounds requiring the user to listen several times and take multiple choice questionnaires. In contrast, manikin auscultation focus on the procedure as the student faces various scenarios where all actions are monitored to provide feedback on the trainee performance. However, simulation-based training poses access challenges due to costs related to acquisition, infrastructure, training, and equipment availability.

1.2. Justification

Multimedia and simulation-based training can provide suitable training scenarios to properly examine and diagnose a patient condition [11]. Manikin-based simulation has proven adequate to acquire cardiac auscultation skills due to its ability to provide feedback [12], within a controlled virtual reality environments exposing the trainee to real-world situations [13], but given the greater cost of manikin-based simulation, multimedia-based simulation is a more promising learning strategy [6]. Current advances in immerse technologies, for both desktop and mobile computing devices, enables the opportunity to innovate, combining not only features of manikin-based simulation training but also transforming the traditional learning method in an interactive way to acquire skills, making use of monitoring systems and enhanced feedback [14].

1.3. Objective

Develop a virtual reality cardiac auscultation app based on cardiac sounds to provide a complementary practice tool for medicine students.

Specific objectives:

- Analyze and characterize the cardiac auscultation procedure to identify the input and outputs of the system.

- Design the subsystem and their corresponding interaction to develop the virtual reality auscultation procedure.
- Validate the VR development with surveys and practical tests to improve the app.

1.4. Methodology

To analyze and characterize the cardiac auscultation procedure, a detailed overview of cardiac auscultation was considered to identify all phases of the examination, from visual inspection to diagnosis.

After conducting the literature review and the characterization of the cardiac auscultation procedure, a system architecture is designed and proposed considering contemporary technologies capable of supporting an user-centred system.

To evaluate the app a usability study is conducted employing the system usability scale, the goal is to measure the grade in which users, more specifically medicine students would feel using the app. To achieve this questionnaire, participants were involved in practical tests.

1.5. Document Summary

In the following chapters, the reader will find the development of the project through five main stages: Literature review, design and implementation, Development of the app, evaluation and conclusions.

- Chapter 2 - Literature Review: The scope and results of related projects or tools used to teach cardiac auscultation are discussed. Cardiac Auscultation learning methods through history until contemporary tools are shown, involving the use of game elements into the discussion, finally, the conclusions of all the content reviewed.
- Chapter 3 - App Design and Implementation: Analysis and characterization of cardiac auscultation is reviewed in order to establish the application requirements and Inputs/Outputs of the system and subsystem, finally, the implementation is discussed and taken into the engine.
- Chapter 4 - Development: Explanation of how the development process was conducted to achieve the goal of a virtual reality cardiac auscultation app, making use of the technologies identified which would better improve the development stage. Also, the development of extra features in the application are explained, those like connectivity to

cloud services and improvement of the traditional information into interactive learning.

- Chapter 5 - Evaluation: The questionnaires used to evaluate and validate the virtual reality cardiac auscultation app are presented, including the testers and how they performed the practical activities to feedback the project.
- Chapter 6 - Conclusion: Results of the tests, feedback concluded by the tests and also feedback the testers gave to the project are presented and discussed in this chapter. As a final conclusion, several propositions are made for future work. Finally, publications made during the development of the project are presented as achievements.

2. Literature Review

The literature review is comprised of related research on learning, considering traditional methods to acquire skills on cardiac auscultation, passing through virtual environments and multimedia solutions to what is predicted for the next years.

2.1. Traditional Tools

Traditionally, pre-recorded audio files were widely used to acquire and strength skills in cardiac auscultation, these are still being used among the trainees or professionals to practice the recognition of heart sounds [2]. Currently, the heart sounds and murmurs can be recorded employing several methods such as stethoscopes attached to microphones, stethoscopes attached to audio power amplifiers, digital stethoscopes, specialized heart sound recorders, and even modern digital stethoscopes which can be connected to a smartphone. It is important to highlight costs, for example, an specialized Heart Sound Recorder costs $3.800 [15], the Thinklink digital stethoscope costs $500 [16] and finally, a homemade electronic stethoscope that would be affordable by almost every medicine student [17]. Additionally, every solution varies in terms of fidelity and functions. The thinklink digital stethoscope is capable of the same functions, but in this case the device controlling all capture sound is an smartphone, and finally, the home-made stethoscope is capable to capture the sounds as the previous solutions because it is still based on a professional stethoscope, but all signal processing should be made by the trainee [18].

Several cardiac auscultation recording databases can be found on the internet, presenting numerous heart diseases. In most cases, the audio files are previously treated with filters to prioritize the desired sound and remove the noise. In other words, it comes to equalize and tune the sounds [19]. Johns Hopkins University owns a repository of sounds, named Cardiac Auscultatory Recording Database (CARD) [20], in which they collected 5,038 recordings from 867 patients, considering patients from 1 day to 80 years old. Another example of an open sound repository is the University of Michigan Medical School [21], which allows playing the audio files from the web navigator and even to download it for free, refer to the Table **2-1** to have an overview of several information sources.

Table 2-1.: Descriptive table of heart sounds library in internet.

Library	Formats	Downloadable	Notes
Continuing Medical Implementation Inc [22].	WAV	Yes	The library counts with 14 sounds with a maximum of 200kb of size per file. Finally, there is an image that represents the timing and the quality of the systolic and diastolic blows.
The Auscultation Assistant [23].	Web	No	It is a web page that offers a well-organized cardiac sound list, designed for the Medical School of UCLA. Each section is accompanied by a sound description in text format.
Medical Training and Simulation LLC [24].	Web	No	Sounds organized by locations on the lunges and heart area. Each sound selection has images referring to the areas where they are best heard, the patient position in which the sound is improved and also, a graphic of the signal in an infinite cycle.
Thinkslabs Medical LLC [25].	Web	No	Sound list that plays repeatedly, active a sound implies to automatically disactive the others. In some cases the sounds has an image describing the signal.
University of Michigan Medical School [21].	MP3	Yes	The sounds are shown in the different chest areas, accompanied by images that describes the patient position and the location where the stethoscope should be located, also each sound is associated with different graphics showing the signal behaviour.
3M Littmann Stethoscopes [26].	WAV	Yes	A list of basic cardiac sounds with a maximum of 400kb of file size.

As cardiac auscultation sounds are still being used, research focused on improving the quality aims to develop algorithms that detect noise which tends to change the morphological characteristics of heart sounds [27] or even, directly analyze the sounds to provide probable diagnostics [28].

Another traditional tool are the standardized patients (SP), whose main objective is to simulate a real cardiac auscultation examination with a real patient. SP can be divided in two categories, as actors trained to simulate a certain disease with standard features or patients with a particular disease and also trained to present the disease [29]. For at least 25 years, SP have been widely used in medical schools to teach and assess clinical skills. This is a very good method of simulation because of the realism that an actor is capable to generate, although, not all diseases can be simulated and even more, when conditions can vary strongly between patients.

Currently, it is possible to carry a huge repository of pre-recorded sounds in a mobile phone. Although, it is an incomplete method to acquire all required skills for cardiac auscultation examination. Even when several sound repositories are open to public, this will not fulfill the experience required for an examination as hands-on practice would provide [30]. On the other hand, the SP looks like an excellent solution, even more when the patient presents a real cardiac condition, nevertheless the availability is limited and it may be an unprofitable solution.

2.2. Manikin Simulation Tools

Simulators are the standard training tool used in medical schools, more specifically, simulation manikins are known because of the grade of fidelity (based on life-like programmed scenarios capable to provide feedback) and the amount of situations they can provide [31].

Patient simulators are capable to simulate almost every cardiac disease by locating the stethoscope over the auscultation areas. Currently, SimMan3G [32] has multiple speakers, which allows independent sounds, with great sound quality and a limited range. Among the greatest fidelity manikins are: S3000 Hal [33], SimMan3G and Human Patient Simulator and Emergency Care Simulator [34]. Access to a manikin simulator is almost an exclusive privilege due to buying, maintenance, equipment training and infrastructure costs. Manikin simulation-based training may be negatively affected by the time taken to practice in the cases where students need to take turns to achieve the learning outcome [11].

The S3000 Hal simulation manikin uses custom stethoscopes which are connected to a computer-based interface allowing to use real stethoscopes to auscultate the manikin. Manufacturers add various features to manikins such as the capability to play the sounds and modify velocity and intensity in real time. Among the disadvantages of manikin-based simulation are the mechanical noises produced by the manikin's internal hardware, these can overlap the lung and heart sounds and distract learners [11].

When it comes to medical simulation, fidelity is the main descriptor that differentiates a simulator capable of imitating a clinical task successfully from a system that would not accomplish its goal. Rehman et al. [35], proposed the multidimensional aspects of a simulator based on engineering, environment and psychological fidelity. S. Barry Issenberg and Ross J. Scales [36], reaffirmed the previous statement by emphasizing on the aspects related to the training goals.

2.3. Digital Media Tools

Digital media can be manipulated and distributed through any computer network, every type of media is encoded by different algorithms and have different information aiming to specific kind of devices.

2.3.1. Multimedia

The internet as an academic tool has a great potential [37]. Among the advantages of multimedia, the connectivity excels, as instructors are capable of tracking their student's progress and assisting the learning process makes of the internet an ideal tool to innovate in education [38].

First-year medicine students of the University of Nebraska Medical Center - College of Medicine, volunteered as part of a multimedia learning program to perform tests and diagnoses on the eye and the ear [39]. To implement the program, the same courses were made in traditional printed books and multimedia material. The multimedia version emphasized on interactivity by including many pictures and QuickTime virtual reality (QTVR) movies of the funduscopic and otoscopy examinations. Finally, the program performed a test related to physical diagnosis skills and tests concerning the human eye and ear, students who used the multimedia version did better, due to time spent, content retention, colour pictures, etc [13].

Virtual encyclopedias like Wikipedia and audiovisual forums like YouTube are the best examples to demonstrate that educative content could have been uploaded or modified by anyone, and in the worst of the cases, the people that upload or modify the content do not have enough knowledge of the topics. YouTube has a lot of videos related to cardiac auscultation, but only few of them are categorized as an educative resource [40].

Currently, advances in mobile computing, multimedia-based solutions can now provide immersive and interactive solutions is suitable for medical learning [41]. Devices such Google Cardboard [42], Samsung Gear [43], Durovis Dive [44], Oculus VR [45], and Microsoft's Hololens [46], are providing mass-market immersive solutions targeting desktop and mobile computing devices easily accessible by medical students.

In the case of Android [47], and its virtual Play Store [48], over 10 applications with emphasis on cardiac auscultation, were found as free and paid versions. The majority of applications have a menu listing all the cardiac sounds, and allow the user to play the sounds, with some presenting text information about the chosen sound and a possible patient heart diagnosis. According to the user comments on each application in the store, ratings difficult determining which is the best application.

2.3.2. Virtual Simulation

As an alternative, virtual environments have proven to allow direct interaction with controlled environments, creating experiences that are the key to learning [49][50]. Virtual environments are capable to offer immersion in a controlled environment, and as result the capacity to provide more feedback to users [14].

Tristan glatard et al. [51], presented a web platform called "Virtual Imaging Platform" (VIP), which facilitates the sharing of object models and medical image simulators, and provides access to computing and storage resources. Besides all its capabilities and power, this is an open-access tool. VIP [51] showed to be capable to run simulations of four modalities and different organs, all of the shown in the web platform. Still, they manifested the web infrastructure to be a limit during the development due to its requirement of knowledge.

Virtual reality is a high-end user interface that involves real-time simulation and interaction through multiple sensorial channels (vision, sound, touch, smell, taste) [52]. The same authors, Burdea Grigore and P. Coifet presents four types of virtual reality:

- Textual VR (interaction, no immersion)
- Desktop VR (interaction, immersion)
- Immersive VR (interaction, high immersion)
- Augmented VR (interaction, no immersion)

Immersion in virtual reality is the level in which the user becomes involved in a virtual world

[52], the immersion relies on the computer-related components. As seen in the previous items defining the types of virtual reality, interaction is a must-have requisite [53][54].

According to the Virtual Reality society [55], there are three types of virtual reality systems: non-immersive, semi-immersive and total immersion. This statement is also made by Paul Milgram and Fumio Kishino [56], they also present the immersion level as a result of the interaction level, no matter if graphics are partially immersive.

Cagatay Basdogan et al. [57], developed a virtual environment for training in laparoscopic prodecures making use of force feedback devices interfaced with laparoscopic intruments. While the user is controlling the simulated laparoscopic forceps, all deformations are shown in the screen to finally, feedback the reaction forces in the simulated device. By this time, they had a lot of limitations, considering the amount of resources used to perform the computer-based training system, in addition to the devices, physics implementation, 3D models and rendering were simplified in order to perform the simulation in real time.

In 2008, the University of California developed a mixed reality human, which is a virtual patient linked to a tangible interface, sharing the same space registered. Communication in interpersonal scenarios consists of not only speech and gestures but also relies heavily on haptic interaction – interpersonal touch [14]. The study results conclude that mixed reality accompanied by haptic feedback may increase social engagement over a human-Virtual Human Interaction.

However, VR can also be an expensive solution depending on its level of immersion and interaction fidelity (a high fidelity haptic device such as the Phantom Desktop can cost more than $25.000 USD [58] and a high fidelity head mounted display like the HTC Vive can cost around $1.149 USD [59]).

Manikin-based simulation have not shown to be superior to VR-based simulation, nor VR-based simulation have shown to be superior to manikin-based simulation. Sok Ying Liaw et al. [6], made a comparison study in which a randomized controlled study group were compared to measure clinical performance of both simulation environments, the results showed each method to be effective but given the requirements of manikin-based simulation, virtual simulation can be considered as a more promising learning strategy.

Kristopher G. Hooten et al. [60], developed a mixed reality simulator to mimic the ventriculostomy procedure, the physical components they user, were a three-dimensional-printed anatomically correct head, complete with simulated scalp, skull, dura and brain substance, and all other equipment required to complete the procedure. They concluded that specifically in the case they were trying to simulate, ideally this life-saving procedure is simulated because an emergent setting may imply unnecessary patient harm.

2.4. Serious Games

Serious games are games designed for purposes different than entertainment only [61]. The main objective of serious games is education and training, these games have a high engaging, motivational and interaction level, not easily captured in traditional online learning environments [62]. According to Kumar and Herger [63], gamification is achieved through player centred design, which involves to know the player, identify the mission, understand human motivation, apply mechanics and finally, manage, monitor and measure.

Serious games have engaged users strongly with learning environments, the desire to achieve a goal involves the student/player, also taking with it detailed monitoring of progress. The users can learn in a quickly and happy mode by playing in the virtual environments [50]. Second life is an example of virtual reality applications like serious games. 3-D virtual worlds offers great potential to creative medical and health educators, but more research is needed into their use in medical and health education [64].

The development of examination skills in a variety of medical procedures is an important component of the training program [62]. Serious games can be applied in several areas, like military, governmental, educative, corporate and health care [65]. Learning based in game elements is capable to engage and involve the objective user in certain situations as considered in the design of a learning route [66].

Serious games applications have been tested in medical environments [67], such as HumanSim (game-based simulation) [68] and CAVE Triage training (Immersive learning environment) [69]. Serious games can make the activities to be more attractive and stimulating, improving the user participation and learning, and also boosting the learner results in every activity, motivating the user to continue using the system [70][71]. Since the beginning, serious games in health care are directed to reduce the medical error and as a consequence it lower the costs in health care [72].

The engaging level a serious game is capable to achieve is generally related to game elements as prizes, points, score charts and challenges. But still, it is necessary to find a balance between challenges and learning [72]. The number of game elements in systems must be limited to avoid losing the objective, or even the way they are implemented must target the main objective in terms of learning. Loose the objective in any of thees elements could result in a bad learner orientation during its learning process.

Score-based system, leader-boards and module division are the most motivational elements for students to use online tools [62]. Yet, it is necessary an exact design achieved through the player centred design outline to implement game elements and adapt those to the application [63].

The Heart Murmur Sim in second life [73], is a virtual environment of education for training in cardiac auscultation, which allows to test the skills of students in this activity. This solutions provide a training simulation in which the trainees make decisions considering the event in which they are participating. The Heart Murmur Sim has been used in colleges and universities in lectures and other learning activities [74]. As a result, according to Maged N. Kamel Boulos et al. [64] students are divided in three groups depending on their level of engagement, The first group is fully engaged, contributing regularly to discussion groups. The second group are sporadically engaged, and contributions are irregularly, finally, the third group may never visit the webpage.

InsuOnline, is a serious game which main objective is to improve appropriate initiation and adjustment of insulin for the treatment of adults with diabetes mellitus [75]. In this case, the system includes a story, tutorials, attractive graphics, funny and a little bit childish icons, wide colour palette, progress tracker, patient feedback, etc. The game allows interactions with the patient and depending on the user decisions, a patient mood bar scales up or down, also a guide partner is during the tutorial to indicate every step in the clinical task, and many other features. As presented before, the use of all game elements may lower the fidelity of the system and might distract the user of its objective [36]. Nevertheless, the game covers all the steps of a clinical task, from patient social treatment to a proper clinical diagnosis.

Another example of a medical serious game is DocTraining, which is a system that simulates clinical cases to assess students knowledge, the clinical cases are created in the same platform, varying symptoms, diseases and samples [76]. In this case they offered an immerse system to use with virtual reality googles attached to a mobile, or even a system capable to be launched in a web-based platform. Some of the main features the system offers are user data visualization and score, set and start a medical appointment, difficulty set up and simulated calls of virtual patients.

Serious games in general have a great potential which can improve the learning and teaching in multimedia environments. It is important to define the main target of the system to finally set up which game elements to use. Prioritize the game elements over the others seems to be important to avoid any distraction or any lost in the trainees objective. Several applications are making use of game elements to mainly engage and motivate the user during its learning process, which can be pointed as the main objective of gamification.

2.5. Conclusions

Several tools have been designed, created and implemented to teach clinical tasks in general. Nonetheless, not all of them are capable to assess the student learning and training, numerous aspects must be considered since the definition of the project's requirements.

The use of multimedia provides the potential of several improvements in a system to teach cardiac auscultation. Traditional information can evolve through interactive, exact, reliable multimedia to properly feedback the user. The manikins are an effective training tool, but due to its cost and physical limitations, make of it hard access too. Nevertheless, virtualization could take all of its major advantages and summarize them in a single digital system.

Several virtual reality applications have been presented, and all of them have shown to be different in terms of immersion. Virtual reality applications like The Heart Murmur Sim [73] and HumanSim [68] are achieved making use of a non-immersive virtual environment displayed on screen, but in the case of applications like DocTraining [76] or CAVE Triage training [69] the virtual reality is only achieved if the immersion is high, being this immersion given by additional equipment than only a screen.

Serious games in general have a great potential which can improve the learning and teaching in multimedia environments. It is important to define the main target of the system to finally set up which game elements to use. Prioritize the game elements over the others seems to be important to avoid any distraction or any lost in the trainees objective. Several applications are using game elements to mainly engage and motivate the user during its learning process, which can be pointed as the main objective of gamification.

3. App Design and Implementation

In this chapter the cardiac auscultation virtual reality application design and implementation is presented. This process consists of the analysis and characterization of the steps required to perform a cardiac auscultation examination that allows to determine the input , outputs and procedures to develop the application.

3.1. Analysis and Characterization of the Heart Auscultation

The cardiac auscultation examination is important because it allows through a routine examination to identify possible heart abnormalities [77]. The heart has valves that transports the blood and during this, the blood hits the heart vessels and walls producing vibrations that are transmitted to the thoracic wall, finally these vibrations are listened through the stethoscope. The heart auscultation examination is composed by four main phases, palpation, percussion, cardiac auscultation and documentation.

Before auscultation and just before the percussion phase, the examiner must take a palpation phase over the upper part of the patients body to find out indicators of abnormalities that may impact the auscultation and even the diagnosis phase. The examiner makes use of their hand and fingers to feel the heart beat, loud heart murmurs may also be felt without a stethoscope [78]. Also, palpation can help to identify indicators of previous surgeries that would suggest extra steps to be considered during the auscultation phase [79]. The condition of pulse is determined in terms of frequency, rhythm, tension, filling and size. Along the palpation, the pulse rate and heart rate are established by feeling peripheral big vessels and apex beat, respectively. The pulse can be rhythmic or irregular in order to determine the rhythm. In the case of the tension of the pulse, can be determined by force, which is necessary to stop the pulse in the artery, and the pulse is established in grade of soft, normal or heart pulse. Finally, filling of pulse is the filling of palpated artery with blood during systole and the size of pulse corresponds to the degree of artery expansion caused by pulse waves [80]. After the palpation, the examiner make some tapping or also called percussion, which consist on placing one hand on the patient and then tap a finger on the hand, specifically using the index finger. Different vibrations over hollow and solid areas may determine if various organ are enlarged or not [78]. And finally, the examiner prepares the space for the cardiac auscultation, ensuring the place is quiet and the stethoscope is warm.

3.1.1. Heart Anatomy and Cardiac Sounds

The stethoscope is a cost-effective tool which allows to listen the patient heart sounds. The sounds of the heart are understood as a cycle, which consist of the systole and diastole [81].

1. Systole: The first and strongest sound is located here. Theoretically, the systole is also known as the contraction period, begins with the closing of the atrioventricular valves called tricuspid and mitral, followed by the pulmonic and aortic valves opening [82]. During the systole the first sounds S1 are found.

2. Diastole: Second stage of the cardiac cycle, known as the relaxation period, begins with the aortic and mitral valves closing, followed by the opening of the tricuspid and mitral valves [82]. The second sound where we can find two others extra heart sounds (third and fourth). The second sound is also known as S2 and therefore, the third and fourth sounds are known as S3 and S4.

There are four types of cardiac sounds, in which two of them have higher importance over the others. These are S1 and S2 that have as source the movement of the blood passing through the heart valves, producing the following sounds:

- First heart sound: Produced by the tricuspid and mitral valves closing in the systole. Characterized to have lightly a higher intensity than the second sound [82].
- Second heart sound: Produced by the aortic and pulmonic valve closure at the beginning of the diastole. As we said previously, the third and fourth sounds are found in the diastole [82].
  - Third heart sound: Also known as the "ventricular Gallop", happens when the blood goes to the left ventricle [82].
  - Fourth heart sound: Refers to the auricular contraction [82].

Due to the collision of blood with the cardiac wall and major vessels, the cardiac areas does not match with the anatomic valve location and therefore, it is necessary to auscultate over the blood flow areas projection [83]. The cardiac auscultation examination is conducted by locating the stethoscope over four different chest areas: Aortic, Pulmonic, Tricuspid and Mitral valve area. Important, the diaphragm is better for medium or high pitched sounds, The bell is better for low pitched sounds [24].

When the patient maintains the breath, there is a need to provide a higher quantity of oxygen to the heart, and that is why the cardiac rhythm goes up, in fact this is important to lower the difficulty during the practice [68]. The only difference between male and female auscultation is that due to the breasts, the mitral valve area sounds are lower in women than in men [84]. Also, in a real scenario, the noise of the hospital or wherever the place the examination is taken would make the the difficulty of the examination a bit harder, another case that makes the examination difficult harder is that the sounds can be heard a bit different among all patients, even when they are in the same conditions.

Once the heart sounds are listened, the goal is to diagnose the patient based on the following parameters that can be interpreted from the examination:

- Shape: It is the sound shape related to the behaviour of the intensity of the signal.
- Location: It is the location of the chest where the sounds are best heard.
- Intensity: It is the signal intensity in a 3 point scale, from low to high.
- Periodicity: Phase of the cardiac cycle in which the sound is identified.
- Quality:It is the description the examiner gives to the signal in terms of the sound behaviour.

3.2. Requirements

The goal of the cardiac auscultation mobile app is to provide a complementary training tool for medical students. To accomplish our goal we defined in this section the requirements for the app. The app is designed to support two users, the Instructor and the Student. This is important as it adds realism to the practice and distinguishes from many multimedia and other apps available, since the instructor will be able to customize and follow up the student progressions. Additionally, the app offers two modes, one with the examination practice and other with included game elements to provide a serious gaming experience, since there can be users who dislike games.

Currently, mobile devices are capable of providing a multimedia experience not easily achieved in devices different than smartphones or computers (desktop computers or laptops), and still, the experience can be improved making use of extra devices to provide immersion and therefore a more complete multimedia experience. In this case, mobile devices are the main target of development due to advantages like portability, connectivity, the variety of devices, software capabilities, and the popularity these devices have all over the world.

By the third quarter of 2016, the statistics according NetMarketShare [85], standard in tracking of the market in terms of internet technologies, presented that among all the operative systems for tablets and smartphones, Android [47] is the most used with a 18.03% of participation in the world wide market, followed by IOS with a participation of 17.13%, refer to Figure **3-1**. Each data presented in the pie graph means the participation of a single version of an OP in the world market, so the sum for Android OS versions (from android 4.2 to Android 6.0) is 64.47% of participation.

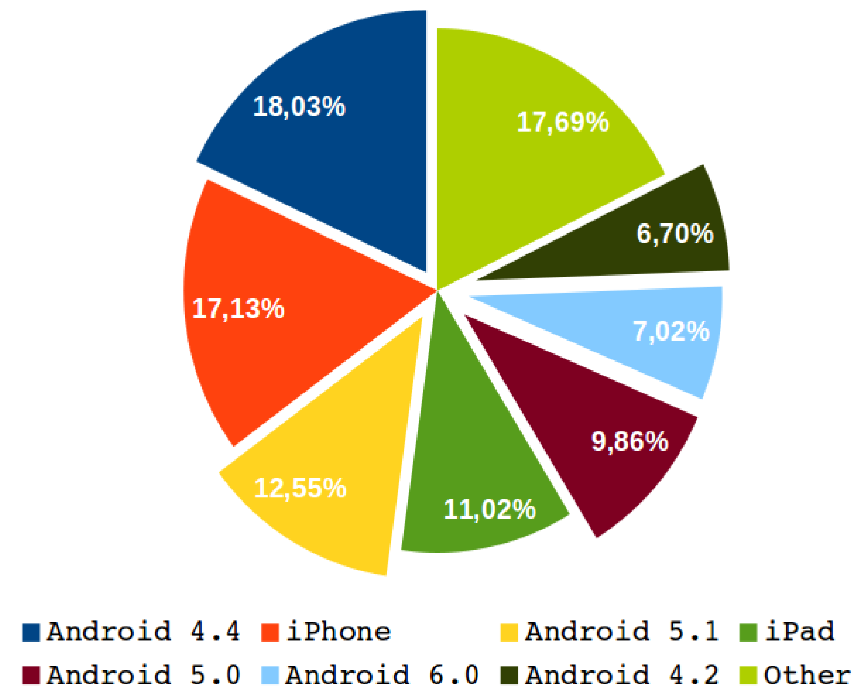

Figure 3-1.: Mobile devices OS statistics

The statics presents Android as the most popular operative system, many causes could support this. Every day more devices are announced with Android, different than IOS which is exclusive for iPhone devices. According to OpenSignal [86], standard on mobile experience, in 2015 smartphones running under Google's operative system were the base software to over 1294 brands. Also, the cost for an iPhone launched in 2016, can be around as lowest for $649 USD [87] and, in the case of Android, the cost for a high-tech hardware smartphone like Asus launched in 2016 is $139 USD. Many other reasons could support Android's popularity, but the previous reasons are enough to address the objective user limitations.

The next step to consider is how to develop the application to the chosen operative system for smartphones. Considering the amount of multimedia to be implemented in the app, involving 3D environments and connectivity to cloud services, 3D engines are the first solution. Native programming for Android may be much more stable but the required time to develop and achieve all objectives in this project would be completely extensive.

Game engine is the core software component for any application that uses 2D/3D real-time graphics, initially developed for computer and gaming consoles, giving the capability of rapid development [88]. Currently, the most popular engines can deploy applications/games not only on computers and gaming consoles, but also on mobile devices, becoming this compatibility feature an important characteristic to choose a game engine. Many characteristics are important to consider when it comes to 3D engines, but the priorities may vary depending on the targeted user, platform, game genre, etc.

Table **3-1**, presents the main characteristics to evaluate in a game engine. All data was gathered from the official web page of each game engine.

Each engine is capable to provide a strong, compatible and a rich development environment. To get into a single engine, for this project three main characteristics are discussed, Compatibility, connectivity and development platforms.

- Compatibility: Amount of devices in which to launch an application. Compatibility for smartphones is available in Unity3D and Unreal Engine.
- Connectivity: Lumberyard has a point in here, its implemented cloud service provide greater opportunities with less amount of time to expend on research.
- Development platforms: In which platforms the engine works. Unity3D is the most compatible in here, it works on Windows, Linux and Mac OS.

Lumberyard is the only platform not suitable make a mobile development. So, the decision relied on Unity3D and Unreal Engine, but further exploration lead to Unity due to its multi-platform capacities (taking in consideration Linux), assets versatility and compatibility, and its huge documentation, not only limited to its official web page but also, all documentation abroad internet discussing from early to professional stages of development in Unity3D. A.

3.3. System architecture

A descriptive system architecture is shown in the Figure **3-2**, presenting the inputs/outputs and their interactions between every subsystem. The system architecture is based on the interaction with mobile devices, the inputs in form of touch gestures which allows interaction with the GUI. Once the user opens the app, two choices are presented, Student or Instructor, each of them open yielding to a different sub-system. Each sub-system requires the user log in but only student's sub-system allows to sign up in the application databases.

Table 3-1.: Comparison among free 3D engines

Specification	Unity 3D	Unreal	Lumberyard
Type	2D/3D	3D and characteristics 2D (mobiles)	3D y user interface editor
Graphics	Since version 5.0 they have a high graphics level due to shaders	Considered as one of the best engines in terms of render and physics	Based on CryEngine
Scripting	Compatibility with visual basic or monodevelop, script editor developed by Unity	Visual scripting by blueprints	Visual scripting
Animation	Mechanim, a System that allows to separate animations and asign or re-asign to other 3D models	Persona animation toolset, skeletons, sockets, blueprints, etc.	Manikin: Animation tool with characteristics as sequencing, transitions, ragdoll physics, etc.
Licence	Free/paid subscription 75$ month	Free until the incomes reach a certain point	It is free, but there is a fee for using the cloud services
Connectivity	Unity is integrated with Unity cloud and still, it has external cloud services	Do not have their own cloud provider but it is compatible with external cloud providers	Amazon works with Amazon Web Service, the biggest cloud service provider in the world.
Language	C # - JavaScript - Boo	C++	c++
Plus	• Complete documentation and forums related to it. • Always updating.	• Frequently crashes. • Its performance in mobiles is getting better.	• Open source • Native compatibility with AWS.

- Instructor user: Administration of a single course in the application, allowing to accept users in the course and feedback students through text messages. The following are options shown in the instructor module.

  Student's feedback: The instructor is capable to follow up the student's performance during the virtual examination. The system downloads the student's information from databases.

  Course administration: Allows enrolling and accepting students into the app. Automatically after a user changes its status from unaccepted to accepted, the system enables the simulation tasks and instructor feedback in the student module.

- Student user: Performs the virtual cardiac auscultation examination, practice multiple cardiac sound cases and revise the feedback.

  Interactive sound repository: Section in which the user accesses the sound repository stored directly in the device. All inputs are limited to touch gestures, where text entry is required.

  Simulation tasks: At first, the system checks if there is any score. Every action during the simulation task and every decision during the diagnosis is stored in device and uploaded to databases in terms of score and textual feedback.

  Instructor feedback: System allows to visualize the student's the scores and performed tasks to assess their progression.

The cloud model used allows to deploy the application as Software as a Service, automatically, the provider manages the resources for what the application asks. One single database stores the information of all the users, organized in multiple tables. Each table has a different function. And the tables designed to work under the system architecture design are:

- Table 1: In this table the student status is recorded (enrolled or not). The access to this table occurs in 2 different situations during the application execution, platform log in / sign in or when the instructor wants to add the user to his course.

- Table 2: In this table the instructor user. Access to this table occurs only in the log-in section.

- Table X1: Each registered instructor has its own table and parameters related to the enrolled students into the course. The access to this table occurs in three different situations during the application execution, when the instructor wants to add/remove a student from its course, when the feedback is updated, and finally to update scores.

- Table 3: In this table, data related to all the medals that can be achieved by the

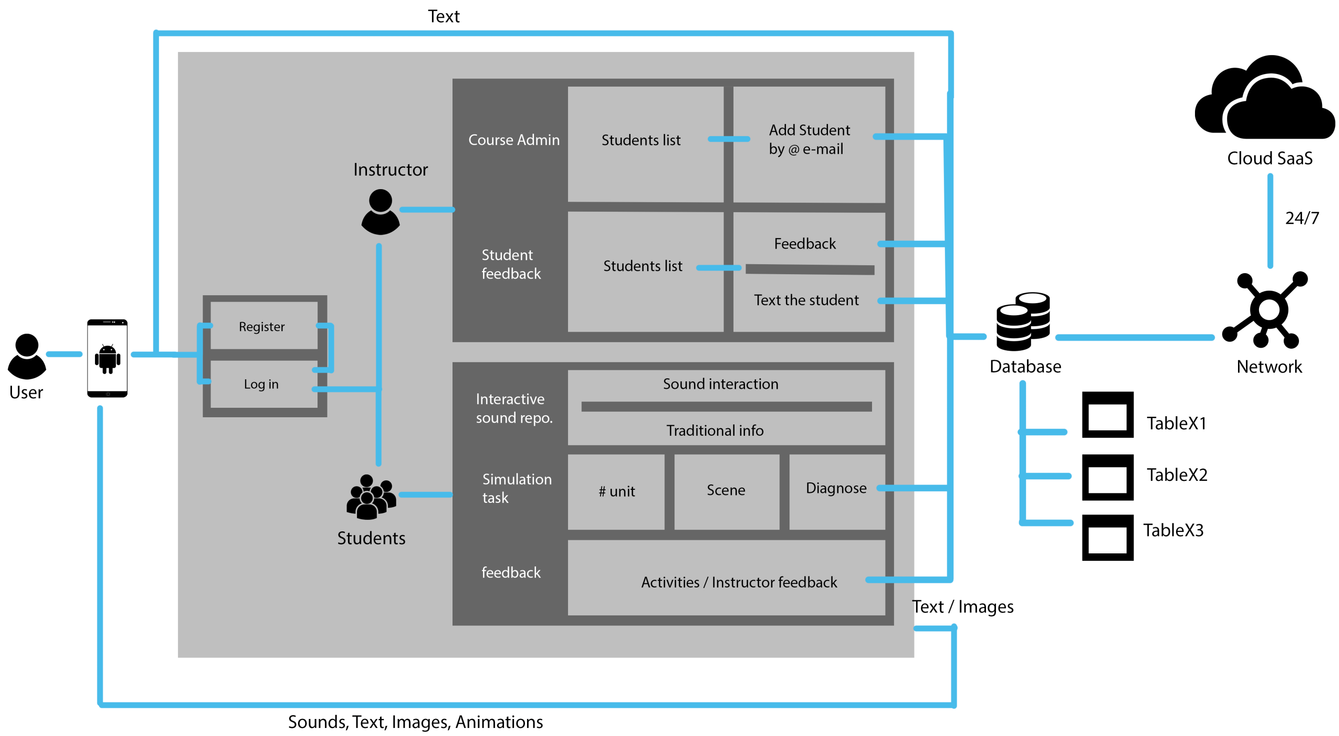

Figure 3-2.: Architecture

students. This table contains information of all the students that have been accepted in a course, each student has boolean information about all the achievements. By default, each achievement is a negative parameter.

For the development of the project, a maximum of registered students were established, at first the limit is five students to register and to evaluate, in this order of ideas, if each student has access to each simulation unit and each evaluation unit has feedback for each role, a total of 50 text files must be stored without counting on sign up and authentication data.

3.4. Use Cases

In this section the use cases are presented as part of the software engineering process within the development process.

3.4.1. Case 1: Log In

Actors: User y System

Pre-requisite: The user must be registered in the system

Normal flow:

1. The user clicks on access.
2. The system shows two field of text, the first one is for the email and the second for the password.
3. The user complete the information required.
4. The user clicks on log in.
5. The system takes time while it verifies the data the user put to finally open the right modules

Alternative flow(S)

The data entered doesn't exist in the database:

1. The system verifies that the entered data is incorrect.
2. The system shows the same text field but without any content in the password text field.

Refer to the appendix B to see in detail the use cases referring to the sections worked in the application.

The student section is characterized by the interactive sound repository in which we find a "DJ module" and a traditional information module in which both are related to sounds. The other section is the simulation main module with a virtual reality patient, where the student can choose a study case, complete the simulation task and finally complete the diagnosis by selecting the correct sound pitch, grade, description, condition, location and radiation. Finally, the feedback section where the user receives a report detailing the scores and achievements. The following figure **3-4** refers to the student section use cases.

The instructor section is comprised of the course administration and feedback. Figure referring the use cases to the professor section **3-5**.

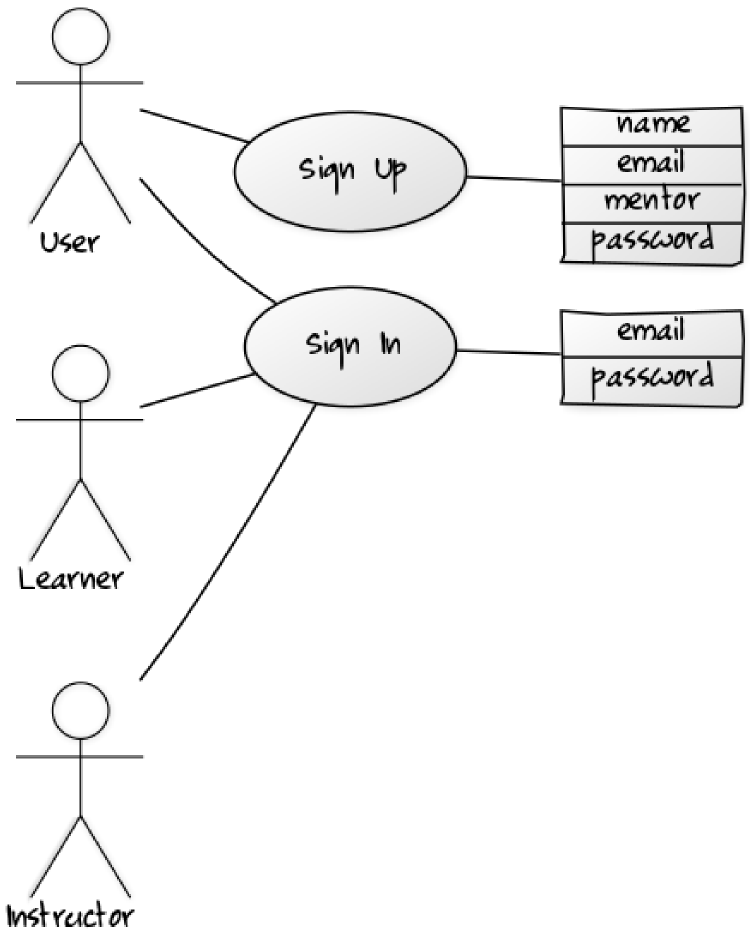

Figure 3-3.: Log in to the system

The game-elements module is divided into three sections, as presented in Figure **3-6**. Achievement's section that collects one-time trophies based on unique hidden actions. The score section is related to activities the user can conduct related to all score obtained in-app, the amount of points are redeemable for prizes and student's ranking allocates the trainees in an anonymous course chart based on every student average score. Finally, the feedback section displays all feedback based on simulations tasks and messages sent by the instructor.

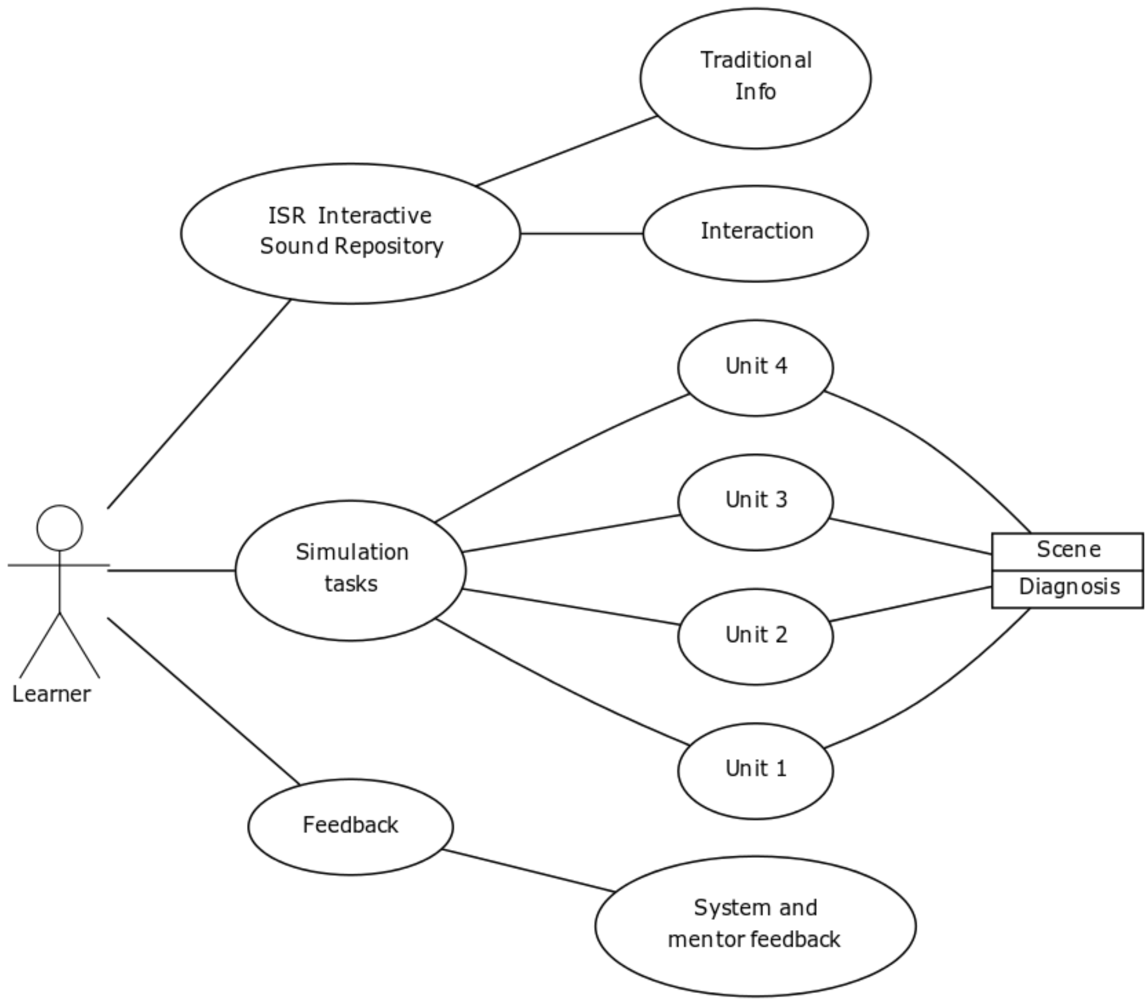

Figure 3-4.: Student module use cases

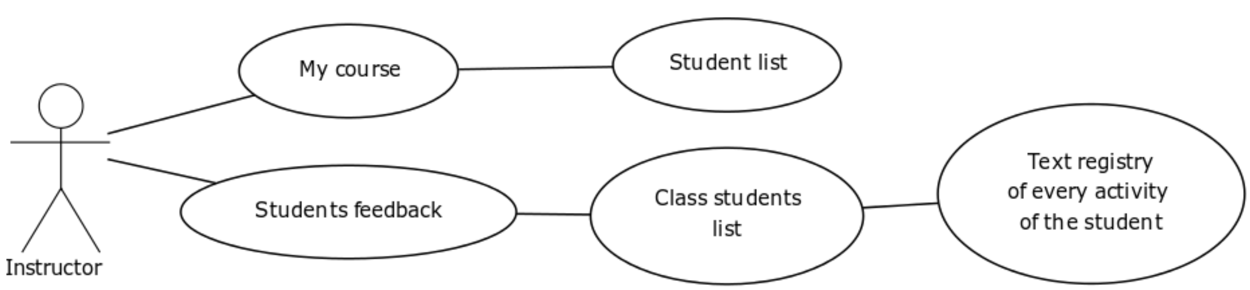

Figure 3-5.: Instructor module use cases

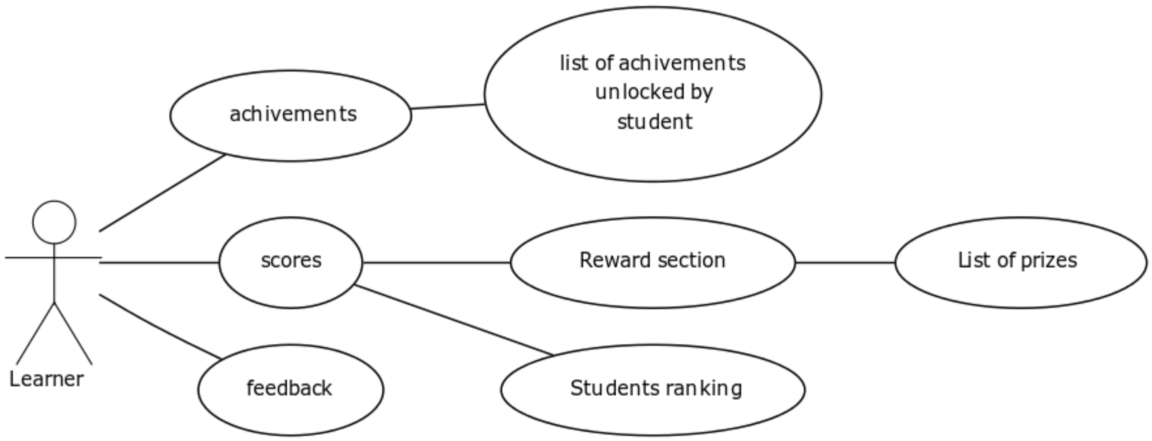

Figure 3-6.: No-game Vs. Non-game version

3.5. User Interface

The interface was based on responsive web design principles [89][90]. As presented in Figure **3-7**, almost every element (buttons, panels, titles) occupies 100% of screen width, the Title section corresponding to point E has a 25% of maximum height and the content is shown in the point G with a 70% screen height. Buttons are also scalable, and they can move within all the G section, occupying a 10.5% height total screen.

Getting more into the interaction with the device, gestures interpreted by the device as inputs are the following:

- One touch interaction: Only one finger touch for touches or gestures.

  Slide: Dragging the finger around the touch screen. The gesture allows moving the stethoscope over the screen area. The gesture also allows rotating the camera around the vertical axis.

  Pinch: The action of a double touch at the same time over the screen and following the separation of touches. This is used to zoom in or zoom out in to the virtual patient.

According to the colour theory [91], colder (blue tones) allows the user to feel less at risk. When using warmer colours (red tones), the user feels a high vital risk. To provide a feeling of safety during the application, cold colours were implemented, as presented in Figure **3-8**. Colours close to the white were used due to the comfortability it offers in a reading environment, also white colours are capable of generating an engaging and relaxing environments [91]. A variety of bright blue colours were used due to its relation with efficacy,

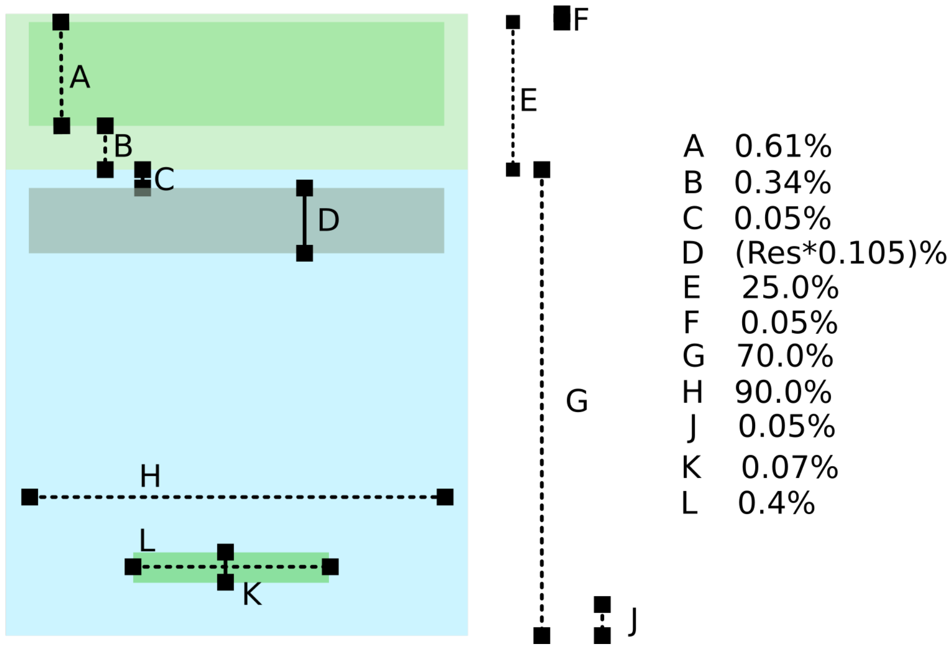

Figure 3-7.: UI design parameters

serenity, calm, reliability and security, same sensation targeted in health centres.

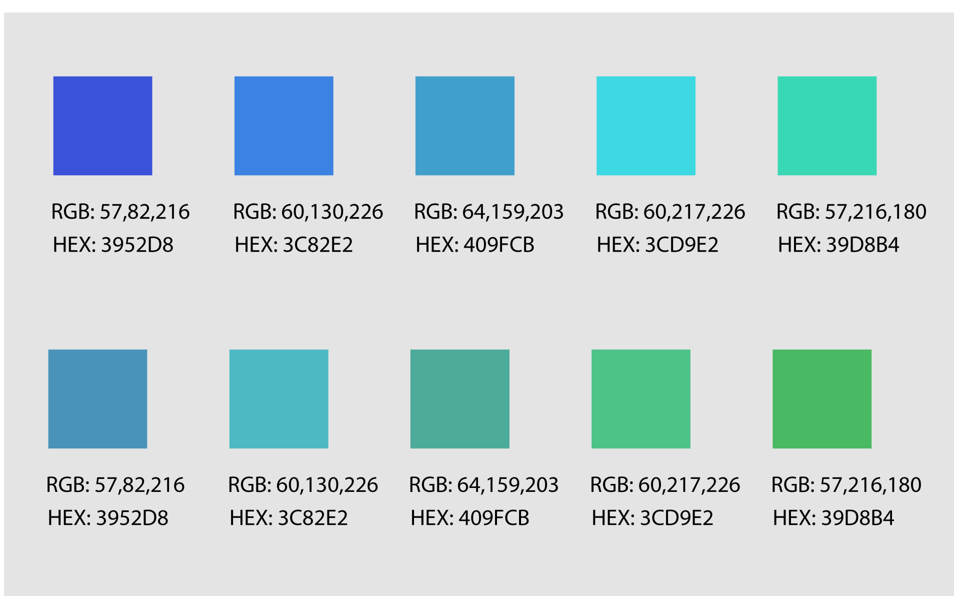

Figure 3-8.: Colour palette.

Regarding the text, Sans-serif characters makes of Calibri a friendly and an easy-reading font type. Serifs are easier to read in printed works, but sans serif fonts are better on computer monitors due to resolution [92]. Another advantage of Calibri font is its compatibility in different text processors, in comparison to other fonts which Calibri is less popular, the recognition by text processors is higher. The Calibri has a lot of variations, like Regular Calibri, Bold Calibri, Italic Calibri, Light Calibri, Italic Light Calibri, etc. As a final note, Calibri was designed for monitor screens [92].

3.5.1. Design of the Application

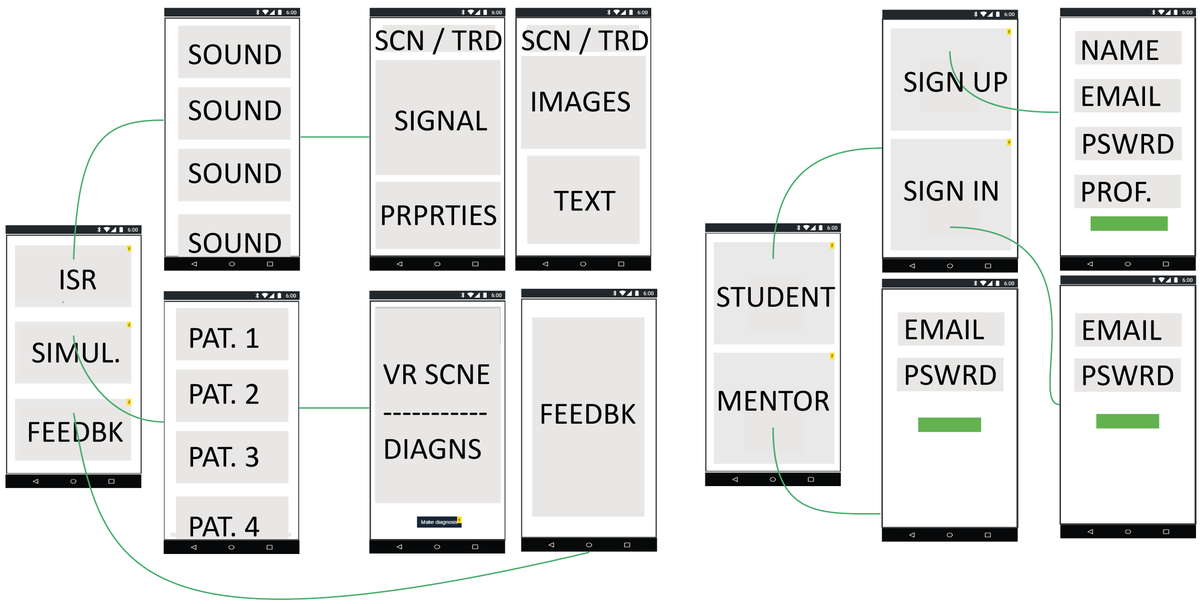

Figure 3-9.: Application log-in user interface / Student module diagram.

As shown in Figure **3-9**, the application has linear interaction, the way to for the last screens, is the same way to go back for the starting menus. The interface is based on two principles to show the content, scroll-down panels which shows different content as the user scrolls down in the screen, and the other principle shows all necessary content in one screen.

As shown in the mockups, the quantity of options are limited (amount of buttons or interactable items), in the case of the Figure **3-9** a maximum of two buttons per sections and, in the case of the Figure **??** a maximum of three buttons per section. This means, the mockups were designed to be simple, guiding the user through the application taking the necessary steps to achieve their final goal.

The student module is comprised of the following user interface elements:

- List Buttons
- Tabs

- Pop up button
- Drop-down list
- Text fields
- Pop up menu

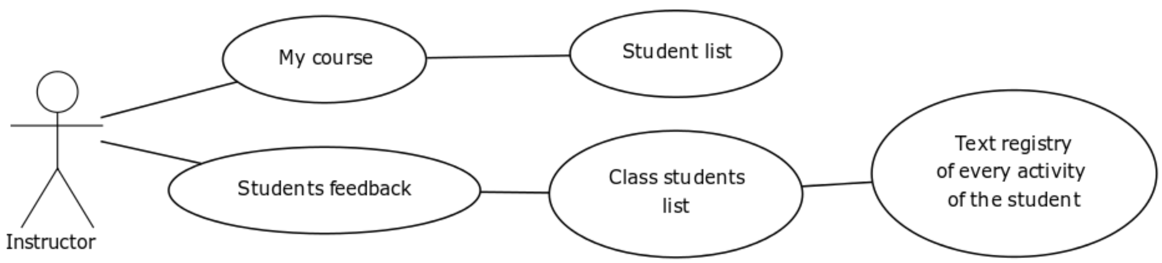

Figure 3-10.: Instructor module diagram.

3.5.2. Game Elements Design

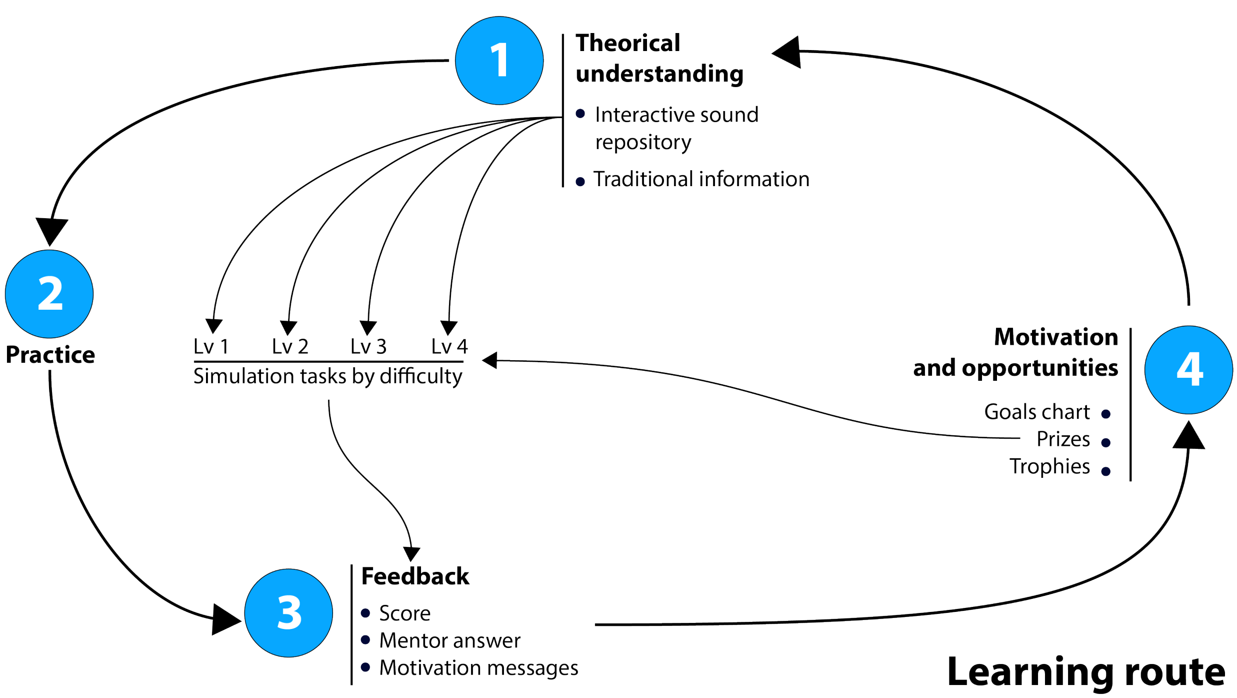

Figure 3-11.: Application learning route

The game elements included in the application are those which most motivate the user according to David Rojas et al. [62].

- Points system: Decisions the user takes during the simulation tasks are evaluated by the system. Each simulation task can have a maximum of 1000 points and a minimum of 0 points, the evaluation parameters are:

  Diagnose timing: This parameter consists to evaluate the time which the user takes to evaluate and diagnose a patient. A time lower than 120 seconds is equal to 100 points as maximum, and higher time implies a score of zero.

  Number of times that the diagnose window is opened: Which consists in counting the number of times user clicks on the button "Diagnose", this with the intention to measure the self-confidence level that a user can have. The scoring method is different to the diagnose timing, in this case all the users start with a score of 100 points and it starts to decrease as the same time the user opens the window diagnose, the 100 points are divided in the number of times the user opened the diagnose window.

  Evaluation order: The order in which the user evaluates each of the cardiac auscultation areas for first time has an impact up to 200 points. The correct order to the evaluation is set by: Aortic, pulmonic, mitral and tricuspid zone. In case the student evaluate only one of the areas in the correct moment, so the sum will be of 50 points.

  Diagnose parameter: As a last evaluation parameter, each of these selected diagnose parameters has a maximum score of 100 points, the evaluated parameters of diagnosis are: Shape, Location, Intensity, Periodicity and Quality.

- Score chart: Scores locate users in a general performance chart, organized by the maximum possible score and its quartiles, each quartil is equal to 250 points until 1000 points. The user is capable to look for its performance but is not capable to look for the others detailed performance. A student is capable to look for the percentage of students that are located in each quartil of the maximum score but they do not have information of each student as a unit. This with the intention to avoid any demotivation, and by the other way, to locate the user anonymously in a chart considering the current score and the others score, highlighting in fact that each student have anonymous scores.

- Division per modules: The course is ordered by difficulty, each patient represents a different difficulty, anyway this does not limit the use, in the case in which the student considers to have a higher knowledge level over cardiac auscultation, so can skip the easiest units.

Game elements implemented in the application aim to engage the user in the learning process and increase its motivation. We propose a section to redeem all obtained scores as follows depending on the instructor criteria:

- Repeat a simulation task - Cost of 650 points.
- Positive point in class: The cost of a positive point in class varies. Cost of 1300 points.
- Score booster: The evaluated unit will have a multiplier of an extra 25% (X1.25) over the obtained score. Cost of 2000 points.
- Remove a grade from class: Cost of 2650 points.
- New patient: It unlocks a new difficulty. Cost of 3300 points.
- High grade in class: Add a new grade. Cost of 4000 points.

Redeem any prizes will subtract score.

In addition, trophies help the student and the instructor to keep track of the progression while using the app.

4. Development

The development process followed up a software development pipeline were the technical requirements guide the process.

4.1. Audio-Visual Components

To provide realism, we created visual contents using 3D authoring tools and image-editing software. The main visual components were the virtual patient and the graphical user interface. This approach was conducted to avoid any copyright infringement.

Since sound is the most relevant media for the auscultation procedure, the sounds for the interactive sound repository were downloaded, and adjusted, making use of the repository from the University of Michigan [21], licensed under a Creative Commons Attribution-ShareAlike 3.0 Licence, which allows to share and adapt its content for any purpose, even commercially [21].

4.1.1. Files and Formats

The images were produced depending on its function in the app, for Icons and 2D animations were exported in PNG format, informative images and textures were exported in JPG format. For 3D animations the maya binary format or .mb was employed. The MP3 sound format was employed to edit and playback the cardiac sounds.

4.1.2. Assets Integration and Optimization in-Engine

Unity3D has an extra compression process and files optimization, that allows improving the app performance. Optimization varies depending on each media (e.g., image compression varies for static images and animated gifs).

Finally, the sounds were imported in monaural format, and play-backed into infinite loops, the sound files were compressed around a 40% of a total file size due to Unity's compression algorithms. The monaural format was chosen to simulate a real stethoscope. In order to allow the audio listener to listen the heart areas, a custom volume roll-off was implemented, based on the space of the scene, the sound starts to loose intensity when the listener is 3.2 units far from source, and the sound is completely lost at five.

4.2. Training Module

Figure **4-1** shows three signals containing the same information in terms of sound intensity but every file has different priority over the desired characteristic through the manipulation of the decibel levels in the timeline. The intensity controller (yellow line) which goes up and down is the factor that determines the volume of the signal in a desired moment of the timeline. Each cardiac sound has separated the first, second, third and fourth cardiac sound, in order to disable and enable the signal by separate in the application.

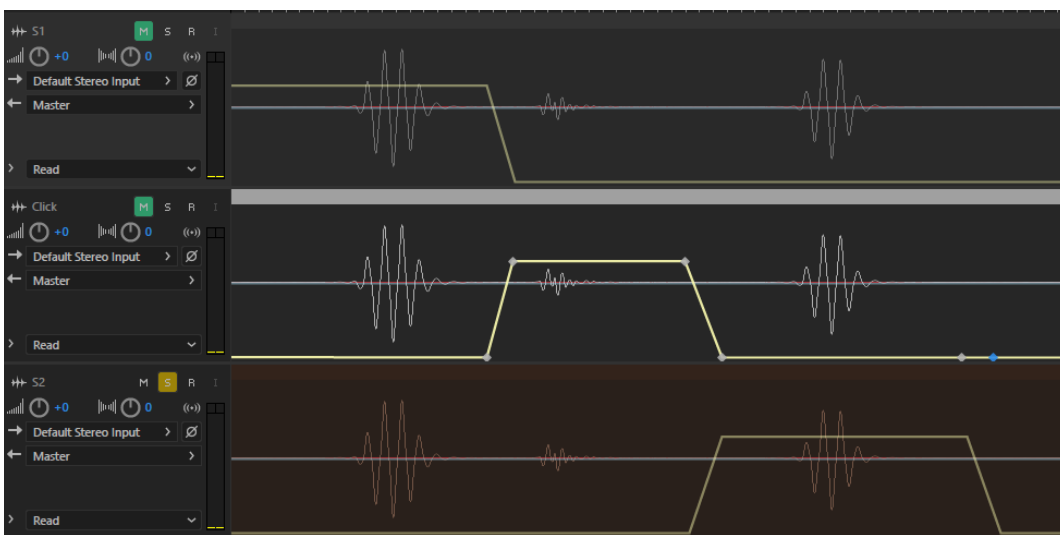

Figure 4-1.: Sound characteristics

The interactive repository sound module presents the information in an interactive (the trainee interacts with the heart sounds), and a traditional form (the trainee look for images and text corresponding the heart sounds). Sound modules can be alternated by using the tabs, were additional information is also presented.

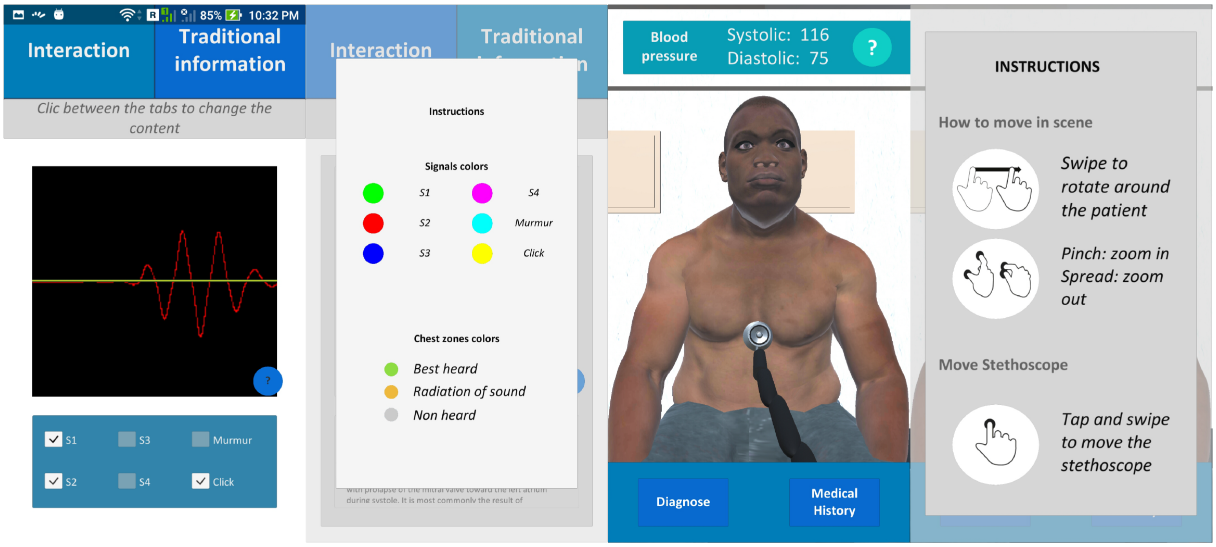

Figure 4-2.: Student module screenshots

4.3. Connectivity to Cloud Services

Networking plays an important role in the app as it allows to record, synchronize and access the instructor and the trainee. To implement the database, Microsoft's Azure services were chosen [93].

Azure allows creating networks, databases and tables. The subscription is a student's subscription, meeting the requirements for the app. Such as, a maximum of storage of 32mb. The Mobile Application resource allows building cross-platform applications to finally add several more services and take advantage of cloud computing. The requests from mobile device considering all content is controlled through the manage of REST API.

Database tables were created to save the trainees and instructor course activities. Authentication was implemented to allow multiple users with personal progress data.

4.3.1. Instructor Module

The functioning of the instructor module depends completely on the cloud services and the connectivity of the smartphone to the network. Both activities, adding students to their course and revising their student's feedback requires connection to databases. The feedback section not only displays information based on the student's performance in activities but also allows the instructor to fill up or even to update the content corresponding to instructor's feedback.

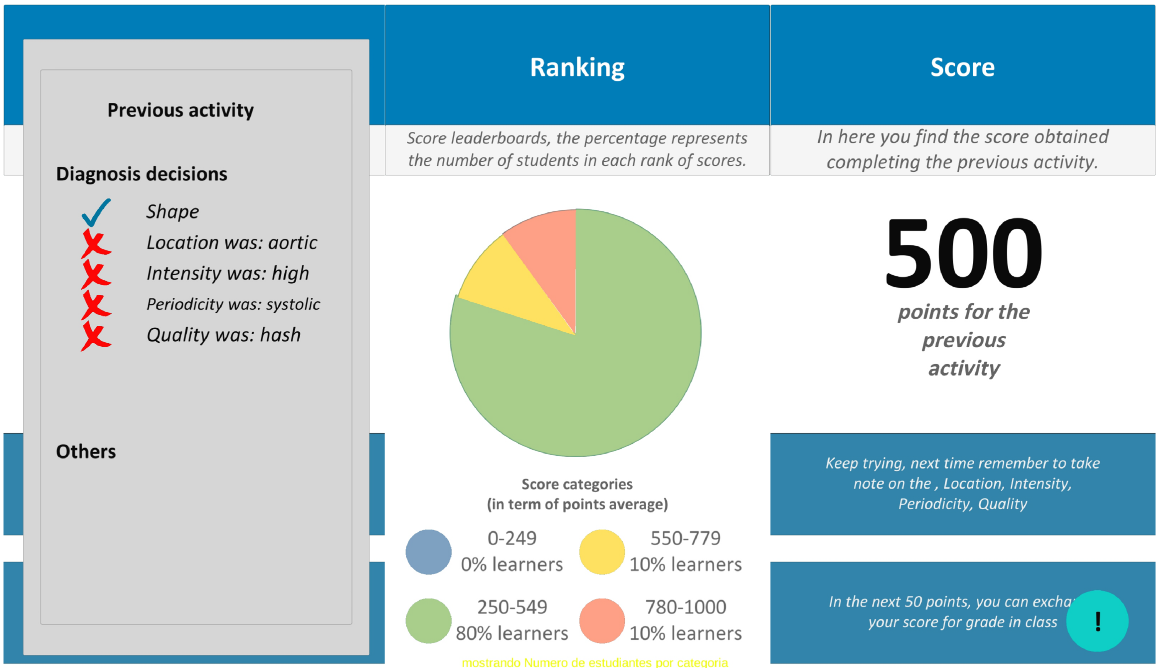

Figure 4-3.: Gamification module screenshots

4.3.2. Game-Elements

Game-elements are implemented all over the student's module, although they are only shown in the student's feedback section. This section presents feedback information and summarize it in terms of scores, achievements, and prizes. After the user accomplish a simulation task, an score is calculated and motivation messages are shown.

5. Results

To validate the app a system usability scale questionnaire [94] was applied to participants involving, game development, computer science and medicine students. Participant's age was between 18 and 24. The variability on the participants was the result of choosing users who can evaluate usability from a game development and a medical perspective

Questionnaires evaluating the level of knowledge of students are not considered as part of the project because it is out of the scope of the objectives. However, a quiz was conducted based on the examination of four cardiac sounds in order to determine how well the participants performed the auscultation with the virtual patient.

5.1. System Usability Scale

The system Usability Scale (SUS) [94] is a 10 item questionnaire capable to measure the usability in a variety of products. Specifically in this case, the SUS is adequate for qualifying this system in a scale of usability.

To measure the usability of the system, 10 students from the programs of Game Development and Entrepreneurship, and Computer Science at the University of Ontario Institute of Technology, and 10 students from the program of Medicine at Militar Nueva Granada University conducted the test through two main stages, a practical stage in which the participants navigate and interact with all the application but the instructor's module, then the testers are introduced to conduct the SUS questionnaire.

In case the participants expressed difficulties when using the app, the participants received assistance from the helper running the experiment. After the practical stage was completed, the participants were asked to complete the SUS questionnaire.

To use the app, participants were given an Android smartphone containing the application and the students were guided through the following protocol to finally fill up the SUS questionnaire.

1. Create an user, filling up the instructor text field with “instructor”.

2. Sign Up with data used to signing in.

3. Navigate around the "Interactive Repository Sound" section with a minimum duration of two minutes.

4. Navigate around the "Simulation Tasks" section until diagnostics done with a minimum duration of three minutes.

5. Navigate around the all feedback sections for a maximum duration of two minutes.

To complete the questionnaire the participants were guided with the same instructions as the previous section. The answers from the UOIT students were separated from the medicine students at the UMNG. To calculate a general overall score over the usability of the system was necessary to consider odd items as different than pair items. In the case for items 1,3,5,7 and 9 the score contribution is the scale position minus one, and in the case for pair items the contribution is five minus the scale position. After the calculations, the score obtained for UOIT students was 65.75, and for the UMNG students the score was 70.75.

As shown in the table **5-3**, the UOIT students resulted in an standard derivation of 16.5 stating that users between a score of 51.25 and 84.25 can be considered as normal, the other participants are dragging the result to any of the extreme points. In the case of the UMNG students (medicine trainees) in the table **5-4**, the standard derivations was 11.45, showing more unity among participant's responses.

The total SUS score of 65.75 (UOIT students), indicates the existence of an usability problems which should be addressed [95]. If the SUS score is under the average score of 68, the application must be improved in terms of usability [96]. A SUS score over 80.3 means an efficient application in terms of usability [95]. The way to improve the system usability must be addressed considering participants feedback. The medicine student's result of 70.75 is very close to the UOIT total score, but is over the average score, it means the application is doing good considering the user objective, but still there are many possible improvements considering feedback obtained during tests. UOIT result is 2.15 under the average and UMNG result is 2.75 over the average usability score, and as a result a difference of 5 points between type of participants.

The feedback provided by participants included major fixes considering design, colours, shapes, messages, interactions, gestures, etc. Figure **5-1**, presents a comparison before and after the provided feedback was implemented, the top interface represents the first stage of development. Participants expressed the colours to be boring, interaction methods were unnatural and shape of buttons and panels were less fancy.

During the development of the application, one conference paper was presented in the 11th annual International Technology, Education and Development Conference. By the same

Table 5-1.: SUS results - UOIT students

Question/Scale	Strongly disagree	Disagree	Centre point	agree	Strongly agree
I think that I would like to use this system frequently	14.28%	21.42%	28.57%	35%	0%
I found the system unnecessarily complex	21.42%	35%	28.57%	14.28%	0%
I thought the system was easy to use	9.09%	0%	27.27%	54.54%	9.09%
I think that I would need the support of a technical person to be able to use this system	23.07%	30.76%	7.69%	30.76%	6.69%
I found the various functions in this system were well integrated	14.28%	7.14%	42.85%	35%	0%
I thought there was too much inconsistency in this system	30.76%	38.46%	7.69%	23.07%	0%
I would imagine that most people would learn to use this system very quickly	7.69%	15.38%	15.38%	30.76%	30.76%
I found the system very cumbersome to use	14.28%	35.71%	28.57%	14.28%	7.14%
I felt very confident using the system	14.28%	21.42%	21.42%	35.71%	7.14%
I needed to learn a lot of things before I could get going with this system	15.38%	23.07%	15.38%	23.07%	23.07%

Table 5-2.: SUS results - UMNG students

Question/Scale	Strongly disagree	Disagree	Centre point	agree	Strongly agree
I think that I would like to use this system frequently	0%	0%	20%	40%	40%
I found the system unnecessarily complex	40%	20%	40%	0%	0%
I thought the system was easy to use	0%	0%	20%	40%	40%
I think that I would need the support of a technical person to be able to use this system	10%	10%	50%	20%	10%
I found the various functions in this system were well integrated	0%	0%	40%	50%	10%
I thought there was too much inconsistency in this system	40%	20%	20%	20%	0%
I would imagine that most people would learn to use this system very quickly	0%	0%	10%	40%	50%
I found the system very cumbersome to use	40%	40%	10%	10%	0%
I felt very confident using the system	0%	10%	30%	50%	10%
I needed to learn a lot of things before I could get going with this system	20%	20%	50%	0%	10%

Table 5-3.: Variance and Standard Derivation of the SUS results - UOIT participants

participant	SUS score	Variance	Total Variance	Standard Derivation
01	50	306.25	272.5	16.5075
02	40	756.25		
03	80	156.25		
04	87.5	400		
05	82.5	225		
06	65	6.25		
07	50	306.25		
08	90	506.25		
09	60	56.25		
10	70	6.25		

Table 5-4.: Variance and Standard Derivation of the SUS results - UMNG participants

participant	SUS score	Variance	Total Variance	Standard Derivation
01	95	588.06	131.31	11.45
02	62.5	68.06		
03	62.5	68.06		
04	62.5	68.06		
05	67.5	10.56		
06	77.5	45.56		
07	62.5	68.06		
08	85	203.06		
09	75	18.06		
10	57.5	175.56		

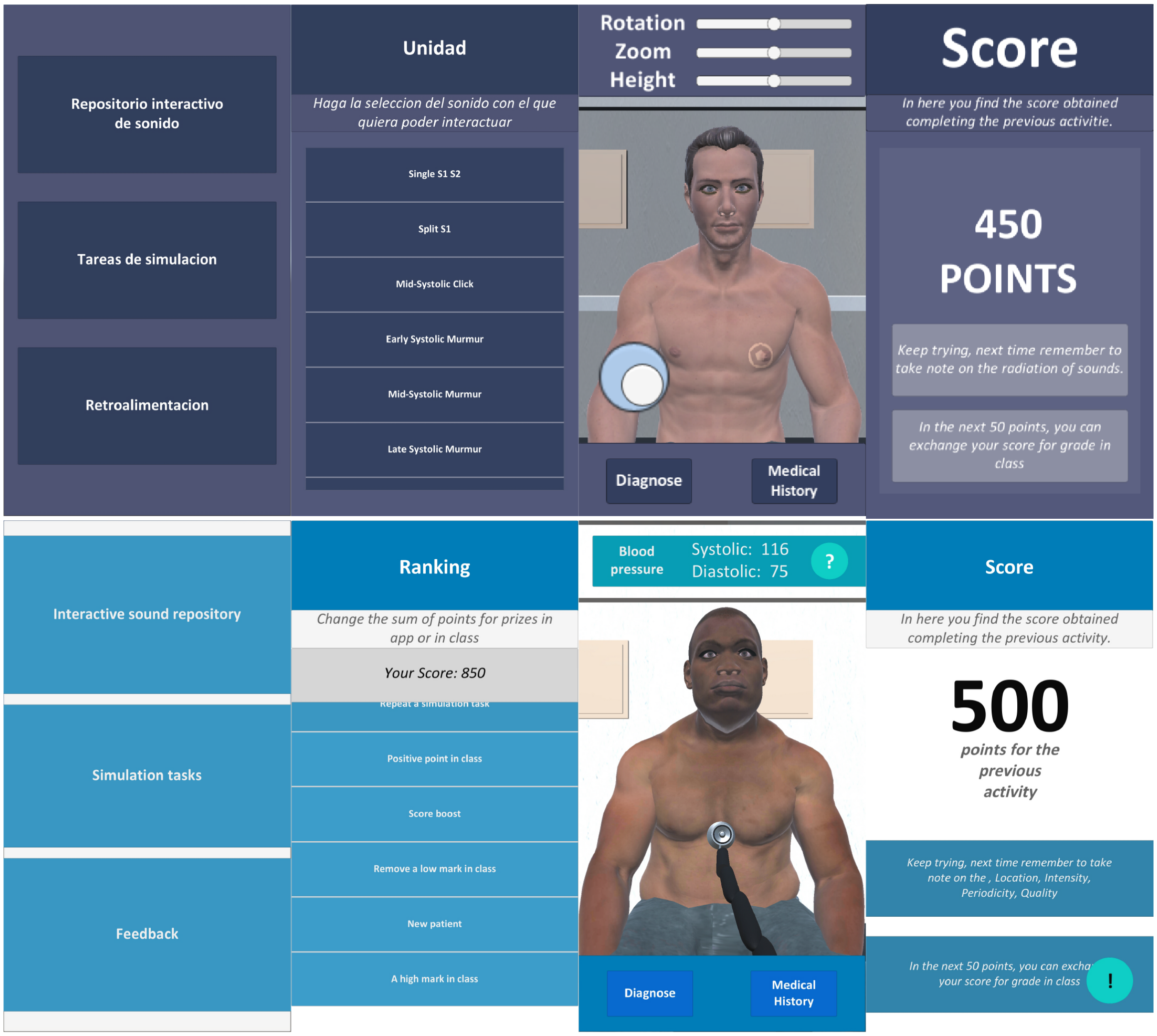

Figure 5-1.: Improvements after SUS feedback.

name of the project, Development of a Cardiac Auscultation Serious Game APP [97].

6. Conclusions

This project made it possible to develop an application as a potential tool to complement cardiac auscultation training.

The cardiac auscultation procedure is comprised by audio-visual and haptic feedback, all of which can be provided by a smartphone which allows full device functionality and capabilities, in addition it allows extra devices attachments to it. This application advantages and benefits could be even maximized if it was programmed with native code, however due to time shortage that could not be done. This application has so much prospect and could be more extensive and advanced.

The application design facilitated user definition and roles, as well as communication feedback between users which allowed game elements consolidation. Interaction methods implemented in the application have demonstrated user interaction in the virtual reality scene.

Natural gestures on touch screens such as swipe, tap and pinch are intuitive and improve the user experience.

The proposed virtual reality system was capable of providing the experience of a cardiac auscultation examination based on the interaction the user has with the stethoscope and the patient. Medicine students expressed interest in the implementation of lung auscultation because of the virtual environment capabilities.

Gathering the simulation scene together with the sound documentation menu provided more realism to the user experience due to the life-like implementation scenario where the trainee has access to the medical history, the cardiac auscultation actions and the documentation in the same scene.

The target user (medicine students) expressed finding the application good in terms of usability, however, several improvements can be made considering the interaction methods that could be achieved in smartphones. From the Game Development and Computer Science participants perspective, the results demonstrated lower usability score. The reason behind this was the slow application's responses, which could be overcome by implementing the application in a native code as discussed earlier and the implementation of more advanced interactions.

6.1. Future work

Several improvements and modules can be proposed for the application. A patient capable of answering the trainees' decisions could improve the interpersonal relation between examiner and patient in a real-life scenario, basing the interaction on conversations, scenario preparation and communication after a medical appointment. The implementation of radiation areas for cardiac auscultation and different patient positions would enhance the experience, making it more life-like scenario. Taking in consideration the interest participants showed on the interactive sound repository, improving this section would involve the creation and implementation of synthesized sounds allowing more interaction with sounds in terms of frequencies, intensity, real-time sounds comparison, etc. Finally, a virtual partner capable of tracking the user experience, completing activities as an assistant would do that could also work as a motivator game element.

A. Appendix: Requirements

A.1. Functional Requirements

The functional requirements are the foundations for the two modes in the app.

- The student controls the sounds to recognize the important characteristics in heart cycle. Controlling the sounds allows adding or removing parts of them.
- The student examines the patients through a virtual reality controlled environment, locating the stethoscope in the different chest places to make a diagnosis.
- In the diagnose section, the students choose the diagnostics from different lists.
- The student accesses reports from their progress.
- The student accesses reports from their instructor.
- The student accesses general ranking section involving all students in a single course.
- The student purchases prizes with score obtained during simulation activities.
- The system registers achievements for the students related to every activity in the application.
- The instructor accesses to a student lists in which can accept students applying to the course.
- The instructor accesses to all students progression based on the systems registry.
- Each user creates profiles to use the mobile app. Profiles allow saving student's data for assessment purposes.
- The instructor profile can create groups of students.
- The system registers student progress based on actions, time taken and decisions.
- The system calculates an average score based on every activity in the simulation tasks.

- The system allows users to create students accounts and apply to intrusctor's courses based on name.
- The system creates a data space for each user in the following tables: Student, Prof-Name, Achivements.
- The system receives up to two touches for interaction.
- The system stores in database instructor's answers to students.
- The system shows in screen the progress for reporting and query times.
- The system has no verification for entrance into the databases.
- The system deletes all info related to the users each time the user starts.
- The system downloads all info related to the user at logging and stores it in the device.
- The system connects to the cloud services to make changes in databases only.
- The system allows to keep the application open in background.
- The system interface works based on responsive design.

A.2. Non-functional Requirements

- The system has good performance in devices with recommended specifications: Minimum Android 4.1 (API level 16), 1Ghz processor, 1Gb ram, 4" screen size and a dynamic storage space.
- The experience with headphones is improved.
- The system supports screen inputs, from a single touch to a multiple touch gestures.
- The system allows the access to profile data when internet connection is available.
- The system performance must be stable.
- The system is understandable, all user without any disability can understand and use it.
- The data security is subject to the security that Microsoft Azure offers as a service provider to host the databases and server.
- The system periodically may update by the user approval to maintain the security and

fidelity of data.

- The system takes less than three seconds to change between scenes
- The system may take less than five seconds for reporting and query times.
- The system is capable to store up to 32mb of information in databases.
- The system availability is 24/7 but cloud maintenance scheduled times.
- The system is scalable in terms of students, simulation units and cardiac sounds.

B. Appendix: Use Cases

Use cases per module, starting with the shared modules between the student and instructor role, followed by separated section specifying the use cases for the student and instructor module. Finally, in the student module, exists a section specifying how the module is modified by the game elements.

B.1. Log-In to the Application

B.1.1. Case 1: Log-In

B.1.2. Actors: User and System

Pre-Requirements: The user must be previously registered in the system

Normal Flow:

1. The user clicks on the Access button.
2. The system shows 2 text fields, the first one is for the e-mail and the second one is for the password.
3. The user enters the requested data in the e-mail and password text fields.
4. The user clicks on the Access button.
5. The system takes is time to validate the entered data and then, the corresponding section to the user role is loaded.

Alternative Flow(s)

The entered data does not exists in the data base:

1. The system verifies that the entered data is incorrect.
2. The system shows again the text field with the same user entered in a beginning but without any data on the password text field.

B.1.3. Case 2: Enrolment

Actors: User y System

Normal Flow:

1. The user clicks on the button Enrolment.
2. The system shows the text fields corresponding to: Name, e-mail, instructor and password.
3. The user enters in the text field all the required data by the system.
4. The system verifies that the e-mail does not exists in the data base.
5. The system makes the data registration in the data base.
6. The system shows a message saying "user registered".
7. The system goes back to the starting screen.

Alternative Flow(s)

The e-mail has been registered previously:

1. The system says back: The entered e-mail has been registered.
2. The system cleans the e-mail and password text fields, then shows the data entered before.

The text fields are empty or incomplete:

1. The system shows back a message: Please complete the required data.
2. The system cleans the password text field and finally shows the entered data before.

B.2. Student Module

B.2.1. Case 3: Interactive Sound Repository

Actors: User y System

Pre-Requirements: The user must have a student role

Normal Flow:

1. The system shows three sections to access: Interactive sound repository, Simulation tasks and feedback.
2. The user selects the Interactive sound repository.
3. The system shows the interactive repository that is also divided in two tabs: Interaction and Traditional information.
4. The user selects traditional information.
5. The system shows a list of sounds previously stored in the device.
6. The user selects one of the sounds in the list.
7. The system loads images and text attached to the selected sound, and it is also shown in screen.

B.2.2. Case 4: Simulation Tasks

Actors: User y System

Pre-Requirements: The user must have a student role

Normal Flow:

1. The system shows three sections to access: Interactive sound repository, simulation tasks and feedback.
2. The user selects the simulation tasks.

3. The system loads a list of units from the device and are compared to data base, followed to combine the lists to finally show them in screen.
4. The user selects any of the shown tasks in screen.
5. The system loads the objects corresponding the data stored in the device referred to the selected task in the list.
6. The user makes use of the scrolls to modify the position of the camera and clicks on the auscultation areas.
7. The user once done with the examination, clicks on the button Diagnose.
8. The system stores all the steps the user made during the simulation and diagnose as a text data.
9. The system shows in screen the data to complete by the user referred to: Shape, Location, Intensity, Periodicity and Quality.
10. The user completes the required data by the system.
11. The user clicks on Diagnose.
12. The system saves the data in the data bases.
13. The system shows in screen, Task completed.
14. The system shows in screen the menu of the students module.

B.2.3. Case 5: Feedback

Actors: User y System

Pre-Requirements: The user must have a student role and also must have completed any simulation task

Normal Flow:

1. The system shows three sections to access: Interactive sound repository, simulation tasks and feedback.
2. The user selects the feedback section.

3. The system looks in the data base for the completed tasks by the student.

4. The system shows in screen the available units (completed by the user) in a list.

5. The user selects from the list, one of the units.

6. The system loads from the data base the file text referred to the unit.

7. The system shows in screen the file text related to the unit.

Alternative Flow(s)

There is no feedback message:

1. The system shows a message saying, there is no feedback message by the instructor.

2. The system goes back to the student menu.

B.3. instructor Module

B.3.1. Case 6: Add student to the course

Actors: User y System

Pre-Requirements: The user must have a instructor role

Normal Flow:

1. The system shows the menu of instructor with tree available possible options: My course, Create patient and Feedback to students.

2. The user selects the option My Course.

3. The system loads from the data base and shows in screen a list with all the students that have a applied to the course.

4. The user clicks over the name of any student.

5. The system connects to the data base to change the status of the student in the data base

6. The system shows a message saying that the student is being added to the course

B.3.2. Case 7: Students Feedback

Actors: User y System

Pre-Requirements: The user must have a instructor role

Normal Flow:

1. The system shows in the menu of the instructor, three different available options.
2. The user selects the students feedback options
3. The system loads from the data base the registered users in the instructors course and shows those that have been accepted in it.
4. The user selects from a list any of the students.
5. The system loads from the database all the feedback from the completed tasks by the student.
6. The system shows in screen all the feedback loaded.
7. The user texts in the text field an answer to the feedback of the student.
8. The user ends texting the message and press the button OK.
9. The system stores the message in the data base
10. The system shows in screen that the message has been uploaded.

B.4. Game module

B.4.1. Case 8: Achievements

Actors: User y System

Pre-Requirements: The user must have a student role

Normal Flow:

1. The system shows in screen three sections to access: Interactive sound repository and Feedback.
2. The user selects feedback.
3. The system shows three sections related to achievements, scores and professor feedback.
4. The user selects the section achievements.
5. The system loads from the database a list referred to all the unlocked achievements by the user.

B.4.2. Case 9: Students ranking

Actors: User y System

Pre-Requirements: The user must have a student role

Normal Flow:

1. The system shows in screen three sections to access: Interactive sound repository, simulation tasks and feedback.
2. The user selects feedback.
3. The system shows three sections related to achievements, scores and professor feedback.
4. The user selects score.
5. The user shows in screen two sections, students ranking and rewards section.

6. The user selects student ranking.
7. The user loads the score of all student and calculates the average per student to finally locate them in a ranking based in quartiles of 1000 points.

B.4.3. Case 10: Redeem Score

Actors: User y System

Pre-Requirements: The user must have a student role

Normal Flow:

1. The system shows in screen three sections to access: Interactive sound repository, simulation tasks and feedback.
2. The user selects feedback.
3. The system shows three sections related to achievements, scores and professor feedback.
4. The user selects score.
5. The user shows in screen two sections, students ranking and rewards section.
6. The user selects rewards section.
7. The system loads from the database the total of score that the student has and shows it on screen.
8. The system shows in screen a list of all the available prizes to redeem with the available score.
9. The user selects any of the prizes to redeem.
10. The system subtracts the redeemed points from the total score and shows the left in screen.
11. The system stores in the database the change of score and make the update of it.

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