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Virtual Patient: Development of a Clinical Cases Simulator as a Tool for Medical Education

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Abstract

Despite undeniable advances in medicine, medical errors still remain a problem that threatens healthcare professionals. An aggravating factor was the COVID-19 pandemic: as the number of cases of the disease increased, health centers began to limit student access, representing a break in traditional medical education. In countermeasure, the simulation of procedures has figured as an option, as teams can learn and practice in a safe environment. The objective of this work is to demonstrate the developing process of an accessible and functional virtual simulator in order to reproduce clinical situations. The medical students can improve their behavior when in usual or unusual cases. The research was managed through a university project with professors and students of Medicine and Information Technology. The project consisted of three stages: a systematic literature review of the main medical scientific databases; a database of clinical cases development to guide a web simulation structure, with the formulation of the medical consultation; a standard definition via BPMN (Business Process Model and Notation) for the operational organization of the medical services was built. As results: a comparative survey of the simulators on the market was carried out; a flowchart template was developed on the HEFLO BPMN platform for procedures, and an initial simulation structure in a cloud platform. The multipurpose character of the tool is highlighted, and it can be used both in individual studies and in an evaluative activity, mainly because of its editable function, which guarantees its adaptation to the different contexts of medical education.

Keywords: Simulation; Medical Education; BPMN; Cloud Computing.

1. Introduction

Medical errors are defined as “an action or omission in planning or execution that contributes or could contribute to an unplanned result” (Ellahham, 2019). A study conducted in 1999 indicated that, in the United States, approximately 98,000 patients die each year as a result of this type of failure (Kohn, 2000). Despite unquestionable advances in all areas of medicine, this age-old problem continues to lurk and threaten healthcare professionals. Medical errors can have profound ramifications for patients and their families, as well as add a significant cost to medical treatment, and it is extremely important to contain this problem (Dhawan et al., 2017). Faced with this scenario, the simulation of procedures has become a common method for people and teams to improve their skills when dealing with medical situations. By simulating, it is possible to learn and practice the necessary interventions in a safe environment and potentially improve a patient's prognosis when situations do occur. In addition, simulators can identify weaknesses, both individual and team (Ennen et al., 2015).

The simulator allows for hands-on training to some extent without causing any inconvenience to the patient. Since 1960, simulators have been increasingly used to train doctors and nurses (Buck, 1991). Simulation training aims to improve patient safety by improving technical capabilities and eliminating human factors in a risk-free environment. It is especially suitable for process-oriented practical professions. Despite the presence of high technology, there is a substantial learning curve for students and facilitators. Simulation technology continues to advance, offering devices capable of improving fidelity in virtual reality simulation, more sophisticated procedural practices and advanced patient simulators (Sakakushev et al., 2017).

Another motivator, which highlighted the need for alternative options to traditional face-to-face medical education, was COVID-19, the disease caused by SARS-Cov-2 (WHO, 2021). As the number of cases of the disease increased, hospitals began to limit the frequency of medical students in outpatient clinics and hospitals, causing universities around the world to adapt to virtual teaching methods. This represented a break in traditional medical education and demonstrated an urgent need for innovation in teaching methods (Arandjelovic et al., 2020). Given these changes, the greatest concern of medical students in relation to remote teaching classes was in relation to how this knowledge could be applied in order to provide clinical experience (Creutzfeldt et al., 2007; Alsoufi et al., 2020).

The objective of this work is to create an accessible and functional virtual simulator in order to reproduce common clinical situations, so that students can improve their behavior in the face of everyday and unusual cases, providing the chance to actively discuss cases that they rarely experienced during their graduation period. With the simulator, the student will have the opportunity to make mistakes while solving the virtual case without causing damage to a real patient, as well as minimizing the chance of medical errors when faced with the same cases in the actual experience, whether discharge or discharge prevalence. The simulator will have the differential of being fully editable so that professors or any other developer of clinical cases can adapt it to their requirements or didactic needs at the time, as well as altering behaviors that may differ between countries, states or even cities.

As contributions, the following achievements of this research can be listed: a comparative evaluation of the simulators present in the market, with their characteristics and differentials for teaching and their respective usability capabilities; modeling and implementation of a simulator with a robust structure for the emulation of clinical cases, but light and responsive, which can even be used by smartphones, in addition to being editable for Brazilian parameters and protocols; a standardized methodology for defining clinical cases through flowcharts (based on BPMN - Business Process Modeling and Notation) that can lead and guide implementations carried out by those responsible for the computational project; in addition to being a versatile tool aimed at medical education.

For the development of the simulator, an extension and multidisciplinary scientific initiation university project was started, called Health lab 4.0, which is part of the Institutional Scientific and Technological Initiation Program of UniBH, together with the University Center of Belo Horizonte. The initiation included the formation of groups, called "squads". The Squad in question, for the present research, was called Squad IV- Simulation-Virtual Patient - composed of 10 students from the medical course and 5 students from the information technology course, students from the University Center of Belo Horizonte-UniBH, selected from selection process and guided by two professors and two leading students, each representing the respective course. The project also had a partnership with the Universidad Científica del Sur - Peru, in which we received external students to compose the Squad and in 2021 (second semester) it has a partnership with RCS Saúde.

2. Methods

2.1 Bibliographic Research

This systematic review was based in the main databases, such as BIREME, PUBMED, UPTODATE and COCHRANE, were used to search for articles from 2000 to 2021. The articles were selected according to search limits that included: article category, articles published in Portuguese and English, articles available in full on the topic, abstracts of international and national articles without access to the text in its entirety.

The keywords used were: realistic simulation, realistic simulation and health education, realistic simulation and teaching, realistic simulator, realistic simulation and health education, realistic simulation and education. Several articles were found, where the exclusion criteria were: publications in other foreign languages and prior to 2017. In addition, articles that did not address simulators with a focus on clinical reasoning, such as surgical simulators, were excluded. Also, during the research, articles whose methodology was not clear as to the technologies used were excluded, mainly in relation to the environment used for the development of the systems, hosting platform and purpose of using the platform. Continuing the work, simulators that did not use the neural network concept were excluded, an essential part for the development of the next steps of the project. The research took into account steps such as: Outline of hypotheses and objectives of the systematic review; elaboration of criteria for selection of articles; presentation and discussion of results, based on the data found.

2.2 Development Methodology

The professors and students of the medical course were initially in charge of developing a database of clinical cases for the simulator, authored by themselves or based on existing cases, real or not, in order to address topics among the most frequent in the daily life of the medical practice. Then, they started to formulate the medical consultation of the patient in the case, creating the entire process of care, including from admission, anamnesis, physical examination and diagnostic hypotheses to treatment.

Questions and answers were elaborated for each stage of the medical consultation, faithfully simulating a service. For the development of this stage, especially the formulation of medical care, students sought information contained in the most relevant scientific evidence currently. In addition, a spreadsheet was created with the main acronyms present in the simulator, to facilitate the visualization and understanding of the topics covered (Table 1).

After preparing 10 clinical cases, the next step was to implement them in BPMN and then insert them into the simulator.

Table 1: Main Acronyms (in Portuguese)

TERM OR ACRONYM (in Portuguese)	**DEFINITION**
QP	*Queixa Principal* - Main complaint: reason why the patient sought care
HMA	*História da moléstia atual* - History of the current illness - data about the patient's illness that may be guided by the physician's questions.
Exantema	Red patches on the skin can come in many shapes and sizes. Ex: in chickenpox, skin allergies and insect bites.
COONG	*Cabeça, Olhos, Ouvidos, Nariz e garganta* - Head, Eyes, Ears, Nose and Throat: Information from anamnesis or physical examination about these regions.

SR	*Sistema Respiratório* - Respiratory system
SCV	*Sistema Cardiovascular* - Cardiovascular system
TGI	*Trato gastrointestinal* - gastrointestinal tract
Anamnese	Anamnesis: Every part of the conversation during the consultation, everything the patient says spontaneously about the disease or answers to the doctor's questions or the companion's speech.
Propedêutica	Propedeutics: Set of techniques and procedures by which a patient is examined, in order to arrive at a diagnostic hypothesis.
Sorologias	Serology: Tests made with the blood with the material, aims to find specific molecules that belong to infectious agents or indicate their presence.
VHS	*Velocidade de hemossedimentação* - Erythrocyte sedimentation rate. Exam that assesses the patient's inflammation.
PCR	1. C-reactive protein, assesses inflammation. 2. Polymerase chain reaction, evaluates the presence of genetic material from microorganisms.
ECG	*Eletrocardiograma* - Electrocardiogram - test that assesses the electrical activity of the heart, resulting in a tracing of lines
RX	Radiography
EEG	*Eletroencefalograma* - Electroencephalogram. Exam that assesses brain electrical activity, resulting in a trace of lines
TC	*Tomografia Computadorizada* - Computed tomography
ECO	*Ecocardiograma* - Echocardiogram. Exam that performs an ultrasound of the heart and vessels connected to it.
NS1	Serological test (item 12) performed for the diagnosis of dengue in the initial phase.

Source: Authors, 2022.

2.3 Case Modeling via BPMN and Simulator Implementation

For better organization and visualization of the logical sequence of the medical appointment, the application Heflo®, based on BPM (Business Process Management) was used, which enables modeling based on BPMN (Business Process Model and Notation). The application Heflo® was essential for the operational organization of the services built, proposing a logical chronological sequence for the approach of patients to the clinical cases developed (White & Miers, 2008).

Once all the data is distributed in an organized, coherent and rational way, the development of the simulator became possible. To develop the solution proposed in this article, the following technologies were selected in the implementation process (Johansson et al, 2019; Mehta et al., 2018): *Python* (a high-level, multiparadigm language that supports the object-oriented and functional paradigm); *MySql* (is a database management system, which uses the SQL language as an interface); *Figma* (is a graphical user interface prototyping system that allows the simulation of the vector created on the computer as an application and web page) and *Anvil Framework* (is an open source platform, used for full stack development, based on the Python programming language).

3. RESULTS

3.1 Critical Assessment of Market Tools

In order to assist in the comparative analysis between the simulators on the market, a survey was carried out where a priori 13 systems were selected, however, after a previous selection, only 5 were finally designated and the following analyzed: Positive and Negative Points, Cloud Environment, Artificial Intelligence, Input, Output, Mobile Environment, Network Usage, Demo Version and Augmented Reality (Table 2).

Table 2: Main Medical Simulators

ID	Reference	Name	Description	Positive Points	Negative Points
1	Sebastiani et al. (2014)	SIACC	Interdisciplinary Clinical Case Analysis System	It can be used by both teachers and students; In addition to having a dataset, it has a register of information and the possibility of assembling use cases; Also possible to configure difficulty levels	As it is on an online platform, it translates the need for network infrastructure
2	Bez et al. (2014)	SimDeCS	Simulation of Decision Making in Health Care	Easy-to-use system that does not require in-depth knowledge of the IT area on the part of the specialist.	As it is in a web environment, it translates the need for network infrastructure; Developed in legacy technology (flash)
3	Antunes et al. (2021)	Body Interact	Body Interact is a virtual patient simulator that offers well-defined and measurable benefits in health education, training and recruitment..	A graphic simulator where the patient reacts to all his actions and with several possibilities. It has interaction between student and teacher.	As it is 3D, it can trigger difficulties if you don't have enough infrastructure;
4	Barroso, et al. (2018)	Electronic Virtual Patients	The purpose of the eViP program is to create a repository or bank of 320 reused and enriched virtual patients (VPs), which will be made available under a Creative Commons License.	eViP is a system that focuses on reuse having up to eight different concepts. It has a multicultural virtual case bank of reused and enriched patients from all over Europe. It is a system linked to Creative Commons License.	Not available in Portuguese.
5	Bez et al.	SimDeCS	The simulator is	Simple to use, it approaches the	Developed in legacy

	(2012); Maroni et al. (2013)		characterized as a tool that promotes learning inspired by active methods.	theme through direct learning based on problems and their solutions through several methodological aspects. It uses the Bayesian network technique in its neural network.	technology (Flash) which does not have portability in some web browsers.

Source: Authors, 2022.

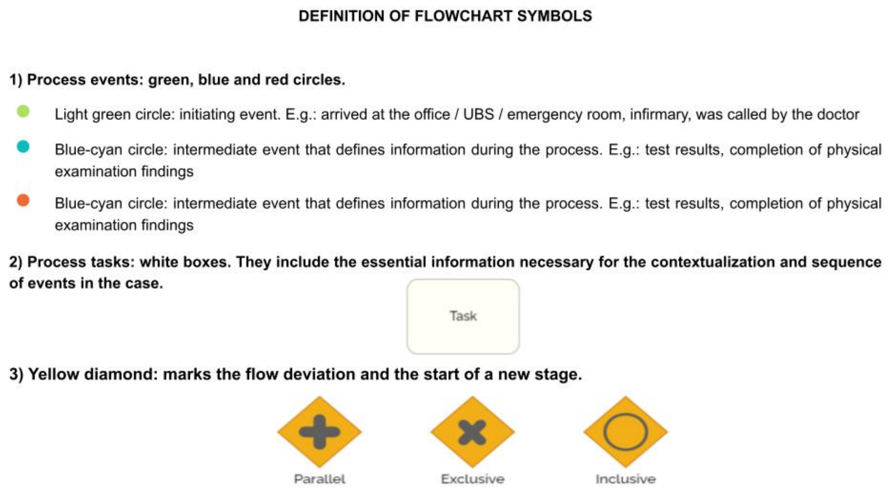
The analyzes were carried out through the use, when available, of the platforms, in addition to the study of the available documentation. The evaluation criteria ranged from the user experience view (usability, simplicity, friendly interface and affordance) to the computational approach focused on the platforms and technologies used in the development of the tools.

Among the simulators analyzed, the ones that stood out the most for their functionalities were the Body Interact, which uses virtual reality in a 3D model to run its clinical cases and is available both on a Web and mobile platform for Apple devices, and the Electronic Virtual Patients (eViP) a system that focuses on providing 320 clinical cases on a concise and multicultural basis with a Creative Commons license, however the cases described in eViP have language limitations, requiring their readaptation for use in other regions beyond Europe. However, for the development of the "Virtual Patient" the features identified as opportunities were added to the main scope of the project, such as the development of a responsive web platform with adaptive technology and environment, the non-limitation of clinical case records in its database and portability In this scenario, the responsiveness allows the simulator to run in browsers (web browsers) on any devices with internet access and anywhere, the structuring of the database in a generic insertion model makes its supply much simpler and varied, only the case flow adapted in a BPMN tool is needed, regardless of the language in which it was developed. The virtual reality present in Body Interact is still a future point, as the implementation of 3D models needs an intrinsic impact and performance analysis, which are not relevant for the current phase of the simulator. The results from this analysis were incorporated into a table (Table 2), where we centralized the main information about the analyzed simulators.

3.2 Modeling of Clinical Cases via BPMN

In consensus with the students of the information technology course, the students of the medicine course created a standard template of flow diagrams on the HEFLO platform, which serves as a basis for building clinical case flowcharts in the most appropriate way to be read, interpreted and converted to the dynamics and usefulness of the developed medical simulation application, highlighted in Figure 1.

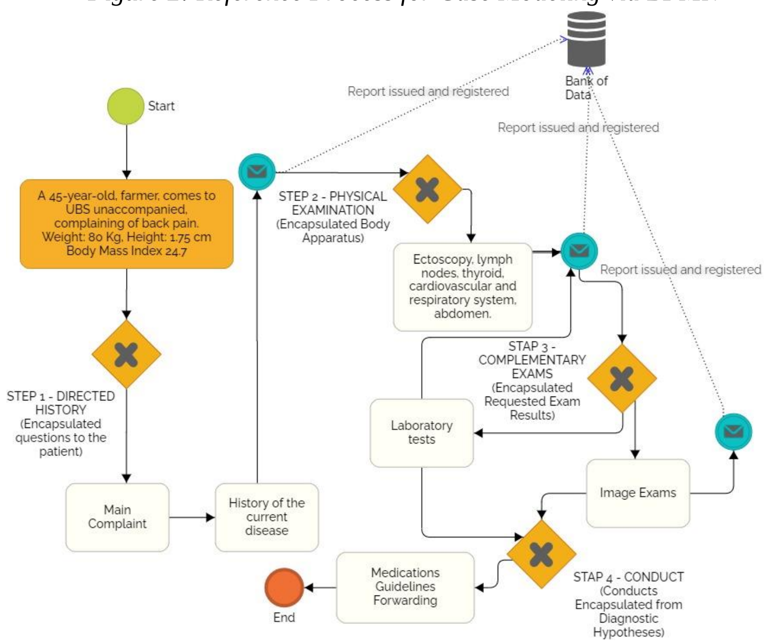
Figure 1: Reference elements for clinical case modeling via BPMN



Source: Authors, 2022

Figure 2 demonstrates a flow of a case. In the first part, the green circle determines the start of the flow, followed by the rectangular task box which, in Figure 2, is colored yellow, and indicates the patient's screening, containing a brief summary of the first relevant general information about the patient and the type of medical professional of choice to handle the case. The color of this symbol represents the level of complexity/difficulty of the case, being green, low, yellow, as exemplified, medium, and red, high, defined at the discretion of the case creator.

Figure 2: Reference Process for Case Modeling via BPMN



Source: Authors, 2022

Following the process flow, there is the first yellow colored diamond with exclusive flow, represented by the "x" positioned inside the symbol, indicating the beginning of the first stage of care of the hypothetical case, conventionally marked by the patient's anamnesis, divided into " Main Complaint” and “History of the Present Illness” (HMA). Both sub-items of the medical interview were indicated through task boxes, in white color, allowing the branching of the HMA box into new tasks, containing the questions (encapsulated in Step 1 of the Flowchart of Figure 1) performed by the physician and information reported by the patient, variables from case to case.

The simulator user does not necessarily need to start the simulation through this first step. Anamnesis was established as step 1 for a better understanding by information technology developers of the correct flow of the case to be inserted in the simulator. All information provided in the anamnesis converges within the flow sequence for the blue-cyan circle, which is a signal to the simulator of the need to generate a report of the answers given to the questions asked while using the simulator. The flowchart proceeds to Step 2 of the medical consultation, which includes a physical examination of the patient. This step is variable for each case and, as in the HMA, it can be divided into unlimited task boxes containing the possible devices of the body to be examined and the findings of the physical examination of each one. The exams to be performed may vary according to the medical specialty, degree of complexity and level of health care in the case. Normally, the basic exams performed in consultations by a general practitioner include measurement of vital signs, ectoscopy, examination of the lymph nodes and thyroid, examination of the cardiovascular system, respiratory system and the abdomen, as well as special maneuvers specific to certain complaints, such as lung maneuvers. Murphy, Blumberg and Giordano.

Step 3 of the “Complementary Exams” follows, which generate instant results, indicated by the blue-cyan circle, upon request for exams within the “Image” or “Laboratory” options. The Step 4 marks the end of the service, including the actions to be taken in view of the conclusions of the information collected by the virtual medical consultation, which can range from the prescription of medications to general guidelines and use of the counter-referral service (referral), with each one of the actions taken leading to different consequences for the patient that will be instantly signaled after being chosen, which may be cure, improvement, partial improvement or worsening of the patient's clinical condition, symbolized in the flowchart by the circle in light red. In the task box of the standard flowchart (figure 2) are exemplified possibilities of behaviors that can also be branched into new task boxes.

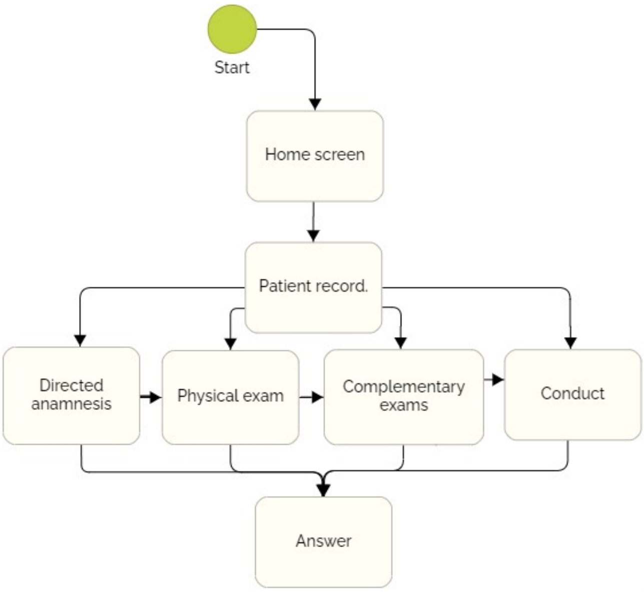
It is important to point out that, despite the various options of questions available from the anamnesis and the physical and complementary exams, the choice of the correct option may be relevant in the assessment of the conduct of the clinical case by the virtual doctor, an artifice to be included in a version expanded simulator. The standard flowchart associated with the caption forms the basis for the translation of clinical cases created to feed the simulator. Based on it, each of the 10 medical students built a flowchart based on clinical cases of the most relevant issues in medical practice, chosen according to their affinity with the topic. Then, one of the flowcharts was chosen by collective consensus to be used as the first clinical case of the simulator developed, based on nephrolithiasis in a male patient.

3.3 Simulator Implementation

The Simulator implementation process, developed exclusively in Python language, was divided into three stages: Back-end, Database and Front-end. During back-end development, the brain behind the simulation was developed. To convert the flowcharts into data usable by the application, a REST API was developed using the MVC (Model-View-Control) architecture and the Flask framework, a small web framework written in Python and classified as a microframework. During this process, the tool was hosted locally and maintained constant communication with the other implementation phases through POST/GET requests, enabling direct access to the database.

The database was developed through the SGBD (Database Management System) MySql, which, being simple to manipulate, made it possible to quickly and assertively enter data and manipulate relationships during the process of preparing the database. simulator. The main entities generated were: User, Clinical Case, Vital Data, Patient, Scenario, Request and Result, each one with its ramifications according to the specificity of the functionality. In front-end development, the application's visual interface, a WEB system was developed that, through simple and usual interfaces, allows the user to simulate a clinical case stored in the database. The framework used in this stage of implementation was the Anvil Framework, here the application screens were developed, which are divided into: Main Screen, Patient File, Guided Anamnesis, Physical and Complementary Examination and finally the Conduct. The model used in this step was based on the prototype developed and brought a clean and easy-to-use interface for users. All important data are described in the Patient File, in addition to a real-time update of the platform. Figure 3 shows the application's structural diagram.

Figure 3: application's structural diagram



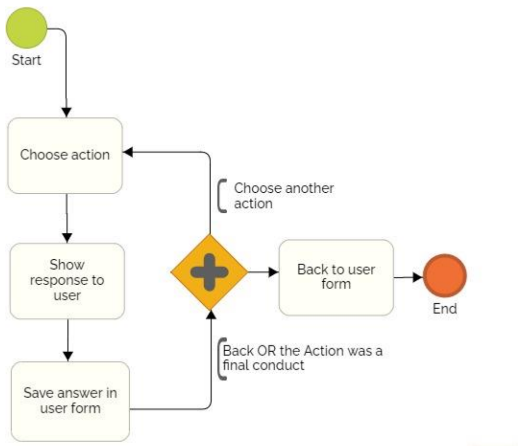
Source: Authors, 2022.

The application has as its initial screen an interface that allows the user to choose which of the registered clinical cases he wants to simulate. Soon after the user makes his choice, he will be redirected to the chosen patient's record where information about the patient will be presented. This screen presents the side menu that contains the actions that the user can perform during the simulation. Each action represents a subgroup of activities to be performed with the patient, namely: *Targeted Anamnesis* (a group of interview questions that the doctor asks the patient. This is where he asks deeper questions to find out about his signs and symptoms); *Physical Examination* (group of actions when the doctor touches the patient in search of any sign that could mean a disease); *Complementary Exams* (laboratory or imaging exams that the doctor may order. A blood test, x-ray, etc) and *Conduct* (and the action that the doctor will take based on the data he obtained during the consultation. So, according to the data obtained, he will prescribe you a medicine, guide you on a diet, refer you to a specialist, among others).

Figure 4 shows the system action flow. To perform an action involving the patient, the user must select an option from the menu corresponding to one of the mentioned subgroups, after selecting it, the actions that can be performed in this clinical case on the patient will be displayed. After choosing an action, the user will receive an answer and at the same time this answer will update the patient's record. The first three subgroups of actions (Directed Anamnesis, Physical Examination and Complementary Exams) are responsible for providing information about the patient's condition, whereas the Conduct is responsible for making changes to the patient's current state, when an action is made in this group the response for the user, it will inform you if this was the correct choice and what impact it had on the patient, and then he will be redirected to the main screen, where the patient's record is located. The system was built to be completely responsive, that is, the simulator elements adapt to the user's screen size so that it can be used on various devices such as a computer, tablet, smartphone and any device with a functional web browser (Figure 5a) and mobile (Figure 5b).

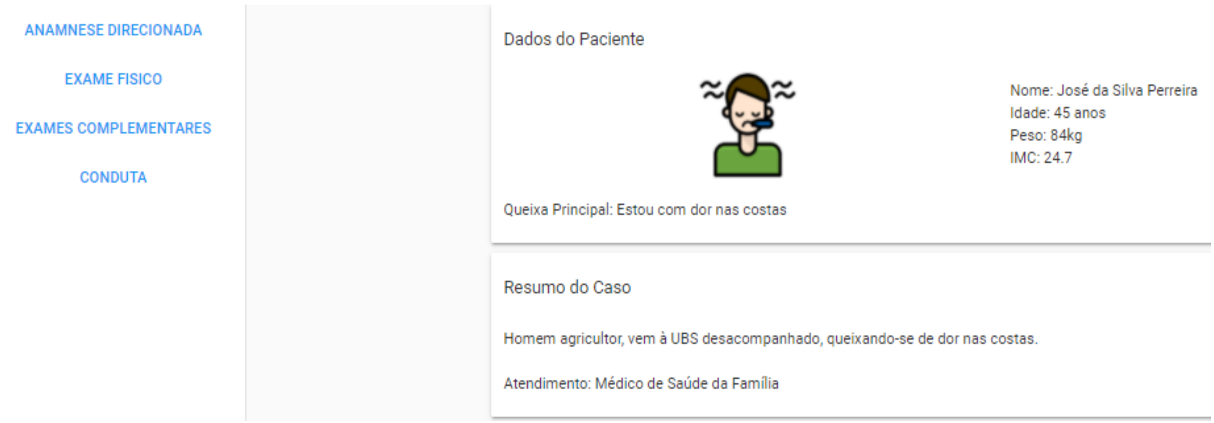
The simulator currently has 2 projects containing 320 kb the folder containing the back-end project and application database and 828 kb the front-end project. The application is hosted in the Anvil Framework application, in the cloud, and can be accessed anywhere, from any device that has internet access.

Figure 4: System action flow



Source: Authors, 2022.

Figure 5: Screenshots Samples



a – web Version

b – Mobile Version

Source: Authors, 2022.

3.4 Interdisciplinary Discussion

The heterogeneity of concepts and creativity in the production was relevant, but considering all the methodological steps and the application of computational resources, it also resulted in difficulties encountered by the participants, such as: knowing how to deal with the modeling of computational processes, the technical terms and the deepening of certain concepts that each area has, the use of technological tools and their way of operating, among other issues that arise when different areas move together.

However, these areas are added and allowed the modification of the way of learning in clinical analysis, modeling and simulation of processes with an implementation of low operational cost, easy and immediate application, made in a university extension and scientific initiation project that promoted the teaching. In this way, the participants benefit from multidisciplinarity and are aware that when computing resources are explored in teaching areas, learning becomes more efficient because it is interactive and stimulating, allowing the adaptation of professional training to the current world, both in the sense of the technological changes that permeate us as in the pandemic scenario we live in and we need to have devices like this.

4. Conclusion

The result of the project is, therefore, very promising. The development of a controlled environment and with the ability to provide a greater margin of error for students, without, however, having deleterious consequences for the real patient, was achieved. The interaction between professors and students of medicine and information technology courses, although challenging, was successfully facilitated. The terminologies and concepts specific to each area have been simplified to the point where communication has been fluid. The result of this is a product of great value to both fields of human knowledge. There are information and skills that will only be acquired in contact with the patient. However, the simulator produced reliably replicates the process of a clinical consultation.

Next, the multipurpose character that the tool confirmed to have is highlighted. Just as it can be used in individual studies, a teacher will also be able to make use of its use in an evaluative activity. In addition, the simulator brings the possibility of being edited, a fact that allows it to be constantly fed with new clinical cases and that it is easily adapted to the different contexts of medical education. All these aspects add very positively to its academic value. Furthermore, the importance of tools like this cannot be underestimated. The pandemic caused by COVID-19, for health reasons, resulted in drastic reductions in the presence of academics in health care settings. Many students, therefore, were harmed by having continued the medical course with distance learning classes, without the opportunity to attend health services, which prevented the complementation of theoretical studies with practical ones.

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