A Reactive "In silico" Simulation for Theoretical Learning Clinical Skills and Decision-Making

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***Abstract*- One of the problems found nowadays in the field of healthcare, and in particular in the emergency services, is that clinical staff members have to make many decisions and they have to implement them promptly. In addition, in the academic field, we must work to train in the competence of decision making with the aim of improving both critical thinking skills and clinical skills. The aim of our research is to develop a conceptual model of the evolution of the Chronic Obstructive Pulmonary Disease (COPD) in a patient, depending on the performances (INPUTS) of the clinician or student (medicine/nursing), in order to transfer that knowledge to a VIRTUAL computerized model. The simulator will enhance a student's training in decision-making and the assessment of acquired skills. Clinical variables, conditions, the evolution of the disease and the input of the clinicians who attend the patient in emergency services define the model. Considering the system configuration, the training offered will be more or less controlled depending on the expertise of the student. Moreover, it will show them not only those scenarios which are more frequent probabilistically, but also those scenarios which are less usual but likely to be encountered in real life.**

Keywords-Simulation; Nursing and Medical Education; Learning; computer models.

I. INTRODUCTION

Chronic pathologies, especially Chronic Obstructive Pulmonary Illness (COPD), are very common in our society and they are responsible for a high number of visits to our emergency services. Correct decision making can result in chronic-pathology sufferers making fewer visits to emergency departments. Nowadays, being capable in the professional field consists of solving problems and situations at work in an autonomous manner. All the knowledge acquired in the formative stages, whether it is higher education or professional education, is not enough since it is essential to have the skills, knowledge, and attitude needed to perform the specific tasks of a job.

Today, unfortunately, medicine and nursing students can learn a great deal about physiopathology, pharmacology, specific care, but they may ignore, or not know, how to use all that knowledge in a stressful situation, such as working in the emergency department.

Drawing from our own career, we have concluded that this deficiency is due to the decontextualization created by formal learning. In the same way, we see that not only students, but professionals as well must, on many occasions, make decisions and implement them as quickly as possible. This many sometimes lead to error due to the inability to assess multiple scenarios quickly when situations are unexpected. If we refer to the mortality data included in the report published in 1999 by the Institute of Medicine of the United States and titled "To Err is Human: building a safer health system", nearly 100,000 deaths were estimated to have been caused by medical errors [1]. Hence, back then, the need to improve the training of the professionals in order to avoid these errors was had already been suggested. The increase in medical errors was blamed on several factors, some of them being the lack of investment in technology and the growing complexity therapeutic procedures. As a result of such report, health educators started to add simulation components to their educational activities.

As stated by Vázquez and Guillamet [2], it has been shown that the use of these clinical simulations reduces the time needed to learn the skills. Figure 1 shows Miller's pyramid, where in the DEMONSTRATE and DO levels the learning processes in simulation are found [3].

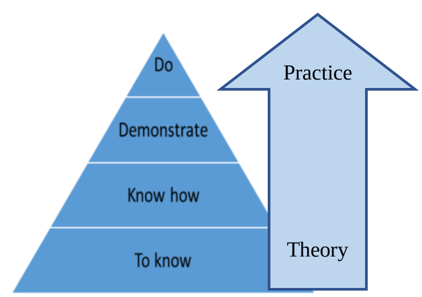

Figure 1. Miller's pyramid

Furthermore, it is claimed that the learning curves based on simulation are better than the curves based on classical learning [4].

As opposed to the potential shown by the implementation of clinical simulation in the degree or professional field, this implementation is not without its challenges. Clinical simulation is not a technology but a technique or learning methodology focused on the participant. Therefore, the main limitation to its widespread application is the high price resulting from its formation in teaching methodology, infrastructure and the excessive amount of time spent by them and the participants in the clinical activity [5].

If we concentrate deeply on the world of simulation, the use of computers encouraged the use of mathematics in the development of physiology and pharmacology, communication around the world and the design of virtual worlds similar to reality [6]. Thanks to this, the development of software to train in the medical field (doctors and nurses) has been made possible. In this software, the user was depicted as a medical or nursing professional and was able to work with virtual tools and perform therapeutic procedures [7].

Authors such as Aldrich [8], highlight that computational simulation is a genre that can help students since it allows self-assessment, real-time feedback, simulations at any time or place without a teacher on site thanks to the possibility of sending messages during the learning process; in short, it makes online learning easier for the student and the instructor. Table 1 summarizes the differences between clinical simulation and computational simulation.

TABLE I. DIFFERENCES BETWEEN CLINICAL AND COMPUTATIONAL SIMULATIONS.

Differences		
	Clinical simulation	**Computational**
Self-assessment	No	Yes
Real-time feedback	Not recommended	Yes
Simulation at any time	No	Yes
Simulation at any place	No	Yes
Teacher needed on the premises	Yes	No
Cost	High	Lower
Major infrastructure	Yes	No
Time dedicated to each activity by the teacher (preparation of the case)	High	Low

Our contribution, in this context, consists of designing a responsive conduct model and its simulation for the creation of an educational resource with the objective of, a priori, training and in the immediate future, adding another applicability based on prediction [9]. This offers us the possibility to evaluate the possible evolutions in the shortest time attainable, according to the performances carried out by the clinician, and thus, support decision-making in the selection of the specific treatment for each patient.

In reference to current simulators, The Synergy-COPD project studies the human body's different functions through computer models at different levels (subcellular, tissue, organ and organ system) [10]. The Synergy-COPD environment is focused on preventive prediction of a disease's evolution through data obtained by the patient in a non-urgent external consultation. In contrast, our project is designed for a hospital emergency department and it allows us to observe the patient's physiological changes in relation to the interventions carried out by the healthcare staff. Authors such as Agustí et al [11] developed a theoretical multi-stage COPD computational model that dynamically integrates and graphically depicts the relationships between the exposure and inhalation of particles and gases (smoking), the biological activity (inflammatory response) of the disease, the severity of airflow limitation (FEV1) as well as the impact of the disease (dyspnea). We want to highlight the research project carried out by Reyes, A., Viciana, R., Díaz, A., and Hermida, R. [12], which is based on the design of an intelligent nucleus for a medical emergency training simulator, specifically in extra-hospital care. The reason why we want to highlight this is that our project resembles the abovementioned study [12] in its decision-making process and the changes in the patient's cardiological condition, yet our objective is focused on the emergency department and COPD patient. Without wishing to reiterate this too much, we have observed that most research projects reviewed are based on the development of models for different systems or diseases, but they always model the pathophysiological progression behavior of the disease. In contrast, our project focuses on the evolution of patients already diagnosed and exacerbated by the pathology and on checking their evolution based on the decision making carried out by healthcare staff.

This article is organised as follows: Section II shows the objectives of the research and the methodology. Section III describes the model of simulation. Section IV displays a conceptual model outline and finally, Section V closes up with a discussion and the work that is to come in the future.

II. RESEARCH OBJECTIVES AND METHODOLOGY

Chronic pathologies, especially Chronic Obstructive Pulmonary Illness (COPD), are very common in our environment.

The general objective of our research is to create a conceptual and computational model that will simulate a virtual patient with Chronic Obstructive Pulmonary Disease (COPD) in the emergency services by the use of modelling techniques.

When the patient goes to the emergency services, they are first attended by **clinicians** in a zone known as "triage", where an initial evaluation takes place. This initial evaluation consists of a few questions (their reason to be in the hospital, personal background, etc.) and parameter values (heart rate, blood pressure, etc.) so as to try to ascertain the patient's level of severity. Once the patient has been assessed, they are classified applying the triage scale used in Spain (I, II, III, IV, and V). Here they are classified in 5 different levels of acuity and priority (from I, the maximum level, to V, the minimum), following the acuity scale used in the Spanish Emergency Services, the *Andorran Triage Model*. We will focus on the patients classified as

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level I, II and III, who will be placed in the **emergency box**. We start our investigation with patient in the Emergency Room (ER). In ER some performances will be carried out in order to know internal data about the patient (for example, monitoring their vital signs, heart rate, temperature.) Some other performances are to diagnose him (for example, requesting an analytical test) and finally, some performances will be carried out to change his evolution (for example administering a drug). In each and every one of these performances, we find variables of both qualitative and quantitative types. Due to their complexity, the variables, many of which are generated by uncertainty, will be addressed through the concept of fuzzification. Basically, this concept is a multivalued logic that allows us to mathematically represent uncertainty and vagueness, providing formal tools for their management. Table 2 shows an example:

TABLE II. SOME EXAMPLES OF VARIABLES

Variables			
Qualitative	**Value**	**Quantitative**	**Value**
Cyanosis (blue skin)	Yes/No	Temperature	Ranges (36-37,5/37,5-37,9/ 38-41)

As we can see, in the performances there are multiple variables that are to be considered but in each performance, mainly in the diagnosis (for example the analytical test) and the change of evolution (for example drug administration), time is essential in order to see the result or evolution, seeing the changes in the variables with the purpose of stabilizing the patient and discharging them.

Our methodological proposal is presented in Figure 2, bottom-up, our methodology stages will be implemented iteratively. The Iterative Model of Spiral Development will be used to develop the simulator. This system iterates permanently over the traditional development cycle of software [13]. The objective of this philosophy is to implement the model in each completed cycle so that a more complex model can be established.

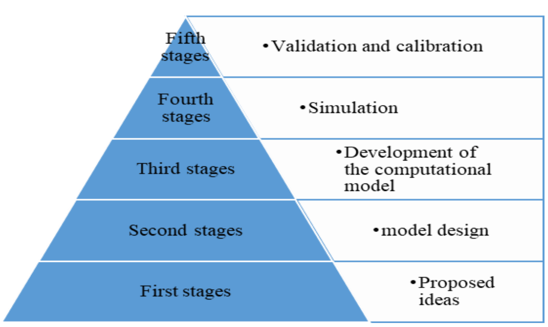

Figure 2. Stages of the suggested methodology

The long-term applicability of this investigation is, as stated previously, to support decision making, based on the prediction of the patient's evolution considering different scenarios. This will result in an important number of variables to work with and that is why we will gain from the methodology suggested, supported by the use of High-Performance Computing (HPC).

HPC enables us to run a great number of simulations, with a view to acquiring a large number of situations that in many cases would not be available without the simulation.

III. DESCRIPTION OF THE MODEL

The simulator will enhance student's training and for this it will have an interface, as shown in the example and its interpretation in Figure 3, obtained from "Pulse, The Virtual Clinical Learning Lab" [14].

The interface will feature a virtual space, as alike an emergency room as possible, where the monitoring of vital parameters, the patient and the clinical staff will be displayed. Additionally, there will be a menu, described briefly below, where the student will interact in order to obtain the data related to diagnosis and performance.

Figure 3. Example of Interface. Image obtained from Pulse. The Virtual Clinical Learning Lab.

To design the model, we propose to use Probabilistic Finite-State Machines, which is a generalization of the non-deterministic finite State Machines. It includes the probability of a given transition into the transition function. We define a finite set of states, a finite set of input, a transition function, a set of possible following states and the probability of a particular state transition taking place. To define the states, the first step has been defining the clinical variables that are to be considered and the value ranges for each variable in each situation. To change the situation, not only has the course of time been taken into consideration, but also the inputs or performances carried out by the healthcare team in the emergency service. The next step has been the creation of a state transition diagram. More details are shown below:

A. *Clinical variables*

According to the group of state variables analysed and agreed on by the Experts Committee, the following designation has been established:

- *Visibles variables*, internal variables of the system that describe the patient's state and that are known, and therefore will be shown to the student/professional (user) when they are interacting with the patient. These variables will be shown as requested by the student, simulating the exploration, the record consulting and the tests undergone in the emergency room.

- *Not visible- monitored variables,* (internal variables of the system that describe the patient's status but that are not available to the user when they take decisions while interacting with the patient). They are taken into account in the state changes.
- *Complementary tests variables* (variables that are finally shown if requested, after a predefined period depending on the test.

B. *State*

The virtual patient's state is conceptually defined by the variables described above that determine the physiological time of the patient. The change of state shows changes in the variables depending on the evolution of the pathology and the decision making by the clinician and thus it will put together a new status. Each variable has a predefined set of values. The specific values that have the variables will determine the patient's specific state. Figure 4 shows an example of state:

Key

Ei=Initial status, Cy= Cyanosis yes, Ty= Tirage yes, Sy=Sleepiness yes, HR=Heart rate, FR= Respiratory rate, PosF= Fowler position, Sat= Saturation, T=Temperature, AuS=Auscultation, GasoT1= arterial blood gas type1, AnaT1=analysis T1, RxT1= X-rays type 1, HemoT1= blood culture type1.

Status 1 [(Cy), (Ty), (Sy), (PosF), (HR<100), (FR>20), (Sat<80), (T 38-41), (AuS), (GasoT1), (AnaT1), (RxT1), (HemoT1)]

Figure 4. One specific example of state

C. *Inputs*

We define as *Inputs* the decisions or decision making of the clinician in order to make the patient recover physiologically, involving a change in the variables that constitute the status, and turning the previous status into a different one. These so-called *Inputs* have been classified into three different types:

- *Data-attainment Inputs* are those inputs in which the student requests this information. They are related to the visible and non-visible variables mentioned before.
- *Diagnose Inputs* are those inputs that the students request to gather evidence that will help them to make a diagnosis. They are related to the complementary tests variables.
- *Performance Inputs* are those inputs that are related to the performances (drug administration, changing the patient's position, etc.), and what the student will do in order to change the patient's state.

Once the different parts that constitute the model are defined, the objective is to design a conceptual model that is summarised and explained below.

IV. CONCEPTUAL MODEL OUTLINE

Figure 5 shows an example of the interaction in which the input is implemented. This input causes some changes in the status of the conceptual model to take place, considering the time unit, and it will be shown on a monitor to the student through the interface as showed before.

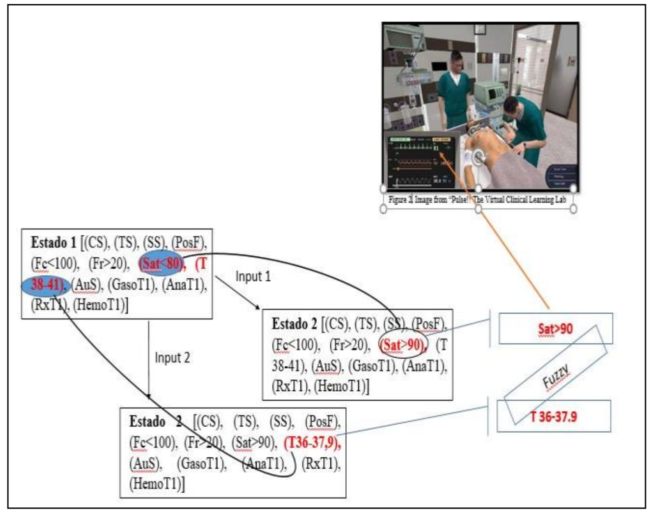

Figure 5. Example of the state changes of the conceptual model.

We propose to use Probabilistic Finite-State Machines. From each possible state that constitutes the model, each and every input will be defined and will evolve toward another state in a percentage of definite probability, considering what usually happens to the patients. Despite this, as mentioned before, the model will have a great variety of state evolution, including those that are more likely and those which are very rare in the health field but which could still happen. In relation to the latter, professors will be able to change the percentage, offering the student or professional these unusual evolutions and controlling the training to a greater or lesser extent.

Regarding some variables that constitute the state in the health field, they generate some uncertainty; there are different ranges and that means we must work with the concept fuzzy. There are different investigations in which fuzzy logic has been used by healthcare workers mainly to make decisions and, more specifically to develop models. In other words, the fuzzy logic theory combines both epistemological and philosophical vision, making it possible to understand how healthcare staff deals with complex, ambiguous and imprecise evens [15].

The verification, calibration and validation process will begin once we have the simulator. In order to calibrate and validate, we will process data on hospitalized patients from two hospitals, Parc Tauli hospital and Vendrell Hospital.

V. CONCLUSION AND FUTURE WORK

Our study´s initial contribution is designing a virtual emergency room so that healthcare staff or students can develop the necessary critical thinking through decision making and make them face situations which they will face in a real environment. Simulation is a way of gaining knowledge from these kinds of situations, which can take place in real life and which on many occasions cannot be tested in a real system before they happen.

Another contribution of this study, and which is also related to knowledge, is the definition of the Method to follow in order to develop the conceptual model that will help us to develop future models of other medical conditions. The methodology suggested will be supported using High-Performance Computing. HPC allows us to make use of the simulator as a real system to carry out a great number of simulations with the aim of obtaining many scenarios; situations which in many cases are not available without the simulation.

As immediate work, and in order to make sure that the suggested model works well, it will be implemented in a computational model.

In order to do so, we will continue working in the conceptual model iteratively to end up generating a model as complex and realistic as possible.

Another long-term contribution is using such a simulator for training students and professionals; and once it has been calibrated and validated, it could be used to support the decision making based on the prediction of the patient's evolution considering of the clinical staff and thus improve the flow of patients in emergency services [16].

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