Didactic tools for understanding respiratory physiology

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Abstract. The challenges in Bioengineering are not only the application of engineering knowledge to the measurement of physiological variables, but also the simulation of biological systems. Experience has shown that the physiology of the respiratory system involves a set of concepts that cannot be effectively taught without the help of a group of didactic tools that contribute to the measurement of characteristic specific variables and to the simulation of the system itself. This article describes a series of tools designed to optimize the teaching of the respiratory system, including the use of spirometers and software developed entirely by undergraduate Bioengineering students from Universidad Nacional de Entre Rios (UNER). The impact these resources have caused on the understanding of the topic and how each of them has facilitated the interpretation of the concepts by the students is also discussed.

Key Words: Respiratory System, Didactic Software and Hardware.

1. Introduction
Bioengineering uses, among others, electrical, chemical, mechanical and optical concepts not only for the study, control and modelling of biological systems, but also for the design of equipment capable of monitoring physiological variables useful for later diagnosis and treatment of the patient. Due to the interdisciplinary nature of Bioengineering, which deals with both engineering and biological concepts, the teaching of certain topics such as the physiology of the respiratory system needs special attention. The comprehension and measurement of the specific variables of the system is one of the starting points for the student to understand the functioning and the different states involved in it. It is with this aim that, at the time of designing a laboratory practical work, the proper equipment is needed. This equipment, however, is very expensive and many institutions do not have the possibility of acquiring them. Sensible and creative proposals are then put forward to reduce these difficulties.

Interactivity has proved to be a powerful tool to make possible the understanding of the qualitative meaning of system variables without any previous knowledge. In the following sections, interactive software will be described. It is based on mathematical models of the respiratory system which have been developed by the students together with the professors of the institution. They aim at developing a lesson based on the qualitative understanding and subsequent generation of the students’ own mental image of the respiratory system instead of only learning a mathematical model or the block diagram of the system.
It is important to point out that all the tasks presented in this work have been developed by 3rd year Bioengineering students with the close supervision of professors from the Laboratorio de Fisiología y Biofísica of the Facultad de Ingeniería, Universidad Nacional de Entre Ríos (FIUNER).

2. Basic Concepts
The entire respiratory cycle is divided into an inspiratory phase followed by an expiratory phase. During this process a large amount of subprocesses that involve a large number of structures occur. Not all of them are exclusive to the respiratory system, but they have the same functional objective: to have the oxygen be joined to hemoglobin and then reach the different tissues in the body and, at the same time, to have the cells expel carbon dioxide.

All these steps that happen simultaneously when breathing are so complex that it is necessary to simplify them to perform the practical task in the laboratory so as to analyze the respiratory movements (RM) by focusing on the routes the air follows, how it makes it and how these variables are measured. This is why the concepts that are emphasized during the laboratory experience are:

- MR Frequency
- Rhythm
- Amplitude
- Duration
- MR relationship to cardiac activity
- Volumes
- Lung capacities in different situations
- Forced expiratory volume (FEV)
- Compliance
- Ventilation/Perfusion relationship
- Pressure in the respiratory system

During the teaching process, it is necessary to involve the senses for the student to understand and assimilate these concepts. It is also important that the students know the equipment and understand the chemical, physical, mechanical and electrical principles that the equipment is based on. These should help them understand the importance of the design and optimization of tools for clinical use.

3. Objectives for the practice
Once the students have identified the main concepts, they have to assimilate them during laboratory practice. After that, the objectives are set to be related to clinical relevance. They are:

- To describe the tools used to make spiographic records and how they function.
- To obtain records of the ventilatory function (spirogram).
- To obtain different lung volumes and capacities by spirometry.
- To solve mathematical problems
- To watch what happens when some of the parameters are changed using simulation software.

The objective of this laboratory work is to make —based on some previous clues— the students perform the tasks in small groups.

4. Didactic tools developed
In this section we describe, chronologically and synthetically, some didactic tools used in laboratory practice.

4.1. “Simulation of human respiratory system by computer” [1] – 1997
It is a simulation based on a computational model of the respiratory system mechanics using an analogue mechanic system. Lung mechanics were modelled as a mass-spring-buffer system that is
coupled to two control volumes belonging to lung and intrapleural space. Thoracic strength acts as external stimulation to the system, generating outputs from it, such as lung flow, lung and intrapleural pressures and different volumes. The model simulates breathing behaviour in pathologies from a mechanical point of view.

4.2. "Simulation of the respiratory mechanics in the lungs and alveoli" [2] - 2003
The classic lung model was used in this simulation. Two phases were considered: inhalation and expiration. Pressure balance was set by differential equations solved by the Runge-Kutta method. As input stimulation a sinusoidal function was used to represent the lung flow during RM. As output pressure, flow and volumes as a function of time are obtained. Alveolar pressure under the effects of surface-active substances is also modelled in this simulation, defining a surfactant function. This can only be used with normal physiological values. Compliance, resistance and frequency are considered constant in each respiratory cycle.

4.3. "Spirometry" [3] - 2003
This task consisted of calibrating and making a spirometer donated by a clinic work. A new valve system and a manometer were adapted to the equipment and an electronic circuit was implemented to obtain an analogue signal, and to form a volume vs. time curve. To undertake this, a small amount of money was required. Figure 1 shows a photograph of the spirometer.

![Figure 1. Fixed spirometer](image)

4.4. "Modelling and simulation of the respiratory mechanics" [4]-2004
The model used consists of one compartment in which the input is different between the inner and the outer parts of the body. In this representation resistance and compliance were modelled as static parameters while pressure fall through the air track was modelled as a dynamic variable through a negative feedback to the system input. The program, named SimResp, simulates basal conditions and the behaviour with changes in the variables that govern the system through graphics.

The surfactant behaviour involved could not be simulated. Neither could the inhalation and expiration phenomena, nor the respiratory rhythm changes.

4.5. "Digital spirometer" [5] - 2005
The spirometer mentioned in 4.3. (Spirometry-2003) was improved. The analagtical signal obtained was digitized to represent linearly the volume changes. Thanks to this, the errors associated with the bad location of the paper and/or the incorrect position of the marker were corrected. The amplification stages and digital conversion were implemented, and the graphical surroundings that store and filter the information to make calculations were developed.
4.6. "Spirometry" [6] - 2007

A screening Lilly type spirometer, belonging to the mechanical resistance pneumotachograph group, was developed and implemented. It causes a pressure fall, proportional to the gas flow that crosses the material used as a resistance screen. This device can be connected to a computer for data acquisition.

4.7. "Design of a software tool to analyze the data collected with the spirometer" [7] – 2007

This work is a complement of the previous one and consists of the design of software for the analysis of collected data.

5. Discussion

In this section there is a numerical reference to each of the previously presented developments. The concepts enumerated in section 2 are emphasized in each experience and are highlighted in bold type.

5.1. “Simulation of human respiratory system by computer”

This software helps the student to understand pressure changes during the RM and the variations that are produced in the compliance, flow, amplitude, capacity and FEV variables facing the different pathologies that affect the breathing system.

5.2. “Simulation of the respiratory mechanics in the lungs and alveoli”

In this case, the simulation shows the curves of pressure, flow and volume according to time, to the pressure-volume loop, flow-volume and the alveolar pressure in relation to the alveolar ratio. These two last items are shown in figure 2.

![Figure 2. Curves of pressure, flow and volume according to time](image)

5.3. “Spirometry”

This device allows data acquisition in an analogical way. Consequently, direct interpretation can be made. The FEV concept, volume and capacities of the lung in different situations can be measured and understood. Figure 3 shows a spirograph obtained with the adapted spirometer.
5.4. "Modelling and simulation of the respiratory mechanics"

The SimResp system shows the curves according to the time of current volume, lung pressure, pleural pressure and the pressure-volume loop. This variability can be modified using the panel of breathing parameters as it is shown in figure 4, on the right side of the screen.

5.5. "Digital spirometer"

This software is able to analyze the data of the test developed with the spirometer in subsection 4.3, taking into account the breathing frequency, the normal volume, the FEV and the lung capacities. The main screen can be seen in figure 5.
4.6. and 4.7. "Spirometry"

These two developments make the acquisition, processing and digitalization of an analogical spirometer signal possible. They enable the calculation of breathing frequency, FEV and graphical representation considering the time of breathing volumes in a simple spirometry. Students are expected to analyze all the processes involved in the measuring and interpretation of the obtained data. In figure 6, the result from a measurement carried out in the laboratory can be seen.

5. Conclusions

Using the different tools described, the students can carry out tests to observe the behaviour of their own breathing system. Besides, the simulations (4.1, 4.2 and 4.4) complement the experimental tests (4.3, 4.5, 4.6 and 4.7) as they increase the possible variations of parameters in the dynamics of the breathing system, enlarging the discussion of the concepts.

It is important for future Bioengineers to understand the complexity of physiological functions, in this case the breathing functions. This can be achieved through the careful analysis of the differences, advantages and limitations that appear between direct tests and simulations.

From the work realized here, we can see the evolution of the students as well as that of teachers that monitor them as regards the quality of the developments achieved. These aspects are also shown in the practical tasks on the breathing system. In these tasks, the students themselves, as users of these tools, carry out changes, improvements and updates of the device. In this way, they produce positive feedback for their future learning.

The available didactic tools today are:
*Simulation by computers dealing with the mechanism of the human breathing system.
*Simulation of the breathing mechanism in lung and alveolus
*How to build a low cost spirometer.
*Modelling and simulation of the breathing mechanism
*Digitalization of a spirometer.
*A screening Lilly type spirometer
*Software to analyse data acquired with a digital spirometer.

All these tools have helped the Bioengineering student to understand the breathing system from an important point of view. Thanks to them, the student is able to know the system in relation to air intake variables and the different states that the variation of these characteristics produces.

Another advantage is that they involve interactivity and the senses in the learning process. Furthermore, and especially for future Bioengineers, these activities promote the use of conceptual knowledge from different disciplines. The students can also arrive to economical, simple and accessible solutions.

Some of these developments are now being used in hospitals, as if they were part of extension activities, internships or final projects (dissertations). The group that calibrated the spirometer and put it to work donated it to a clinic. This group did alike with a similar spirometer, as part of an internship, and it was given to the Obstetrics Service of the Hospital San Roque in Paraná.

On the other hand, it is relevant to emphasize the fact that it was possible to carry out a laboratory practical work with a small quantity of money. This could be done thanks to the efficient administration of human resources, taking into account the high cost of the instruments used.

6. References
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