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Teaching Medical Instrumentation Fundamentals Through Innovation Processes

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Abstract— **The aim in this work was to design a syllabus for teaching medical instrumentation fundamentals where the instruction methodology was based in innovation processes with the clear goal to obtain a medical impact. The premise was that students are more eager to participate and more motivated to study when they see the clear retribution to their academic effort. The key to be effective in this educational method was that students could learn and apply the different phases in the innovation processes. This method was applied to 20 students in the 3rd year of the BME undergraduate program at Universidad Autónoma Metropolitana in México City during 2011. The result was that only 3 students dropped out of the course, one failed and the rest of them obtained B^{++} in average, when the typical student's performance in this type of courses has been C^{+} with 30% of them failing. The conclusion was this type of teaching method not only increases the student's academic performance but it is also a means of transforming what began as university effort into a possible industrial product with medical impact.**

Keywords—**Teaching, medical instrumentation, innovation processes, BME teaching**

I. INTRODUCTION

A. Defining the Problem

Teaching Biomedical Engineering (BME) is a very complex task in which the fundamental theories and principles of biology, medicine and engineering have to be addressed in a world where medical technology is moving forward all the time. The essence is to teach engineering methods to develop technology for the benefit of the patients and to create health related products that improve the quality of life [1].

At the beginning of the 60s most of the BME programs around the world were seen as classical interdisciplinary teaching programs emphasizing electrical, mechanical, chemical, and computer fundamentals. The idea was to provide courses strongly oriented toward solving medical and biological problems but unfortunately there was little concern and experience on how to teach innovation processes in order to produce a real medical impact [2].

As a result of changes, BME education between the 70s and 90s was directed towards an interdisciplinary methodology where the teaching process was oriented to use professors in different expertise areas, teaching together the same courses. Courses where teaching was carried out together, employing engineers with physicians and physiologists, or physicists with medical doctors were the key to detect and solve technological problems in the classroom but once again without paying too much attention to the medical technology transfer problem [3].

Other teaching strategies to solve the not well identified innovation process took the route to name courses using the prefix "bio-something" in order to assure the presence of the engineering in the BME formation as a manner to arm them with many tools or "hammers" as possible. Bioelectronics, biomechanics, biotransducers, bioinstrumentation, etc, were the standard courses in almost all BME programs. The premise of this form of teaching was enough to create in the students the ability to solve medical problems and the capability to detect spontaneously "the nails" which would in turn develop entrepreneurship and innovation processes but the result was limited since the innovation in those years came mainly from small companies and not from the universities [4].

Today, there are new BME curriculum design needs that are more oriented to cover specific medical knowledge-generation demands. For example, the genome and physiom projects have stressed the application of new fields more profoundly related with the medical sciences rather than the classical engineering fields from which the BME originally came. These new demands come from the study of proteomics, metabolomics, biological systems, molecular biology, etc, which are still in evolution at present, but nowadays these disciplines are more aware of how to direct the medical impact, probably because there are implicitly innovation processes [5] [6].

On the other hand, a few of the initial BME teaching courses have evolved, preserving their own identity because they were able to continue to generate engineering and medical knowledge to produce low cost medical solutions. In such a case, it is possible to classify the benefits of preserving courses like the medical instrumentation. Nevertheless, the teaching problem has been the same in the sense that it is quite difficult to create in the students a clear understanding of what an innovation process means, i.e. the academic problem can be colloquially defined as: how is it possible to design a teaching process where "the hammers and nails are in the same jar?" There is no doubt that professors in BME will be continuing to face this problem at the present time and for the years to come.

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B. Defining the strategies

Medical Instrumentation Fundamentals courses have been taught by excellent professors since basically the 70s. Some of the classic books were written by L. Geddes, R. Cobbold, and J. Webster just to mention a few of the important educators in this field in chronological order [7-9].

The contents in these books are not out of date and offer a clear testimony of different teaching strategies. In general terms, they propose: (a) instruction in the fundamentals in measurement theory, (b) analysis of the non-invasive medical instrumentation with characterization of their static and dynamic performance, (c) illustration of specific measurement techniques or medical instruments using details analysis in their electronics circuits or mechanical designs. The idea was that understanding the state of the art always helps in order to solve medical problems. However, none of these books used the concept of innovation processes to instruct students on how to produce any advances in instrumentation with a real medical impact and the corresponding technology transfer as consequence of this approach.

Thus, the aim of this paper is to define a different teaching methodology for Medical Instrumentation courses where the concept of innovation processes is the key for the syllabus design. The first attempt using this methodology was done between 2009 and 2011 and applied to teaching a student population in the third year of enrollment in the undergraduate BME program at the Universidad Autónoma Metropolitana in México City.

II. Methodology

C. The teaching model

A medical instrumentation course based in innovation processes needs to follow a teaching model which should be very consistent with the five typical phases of any innovation process as it can be seen in Figure 1.

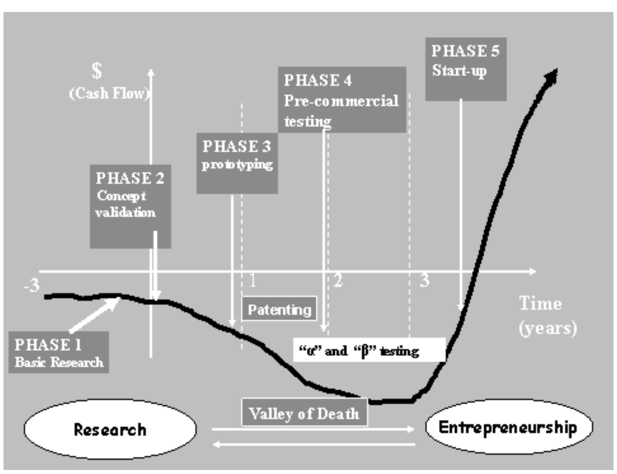

Figure. 1 An innovation process is shown where the cash flow (vertical axis) in time follows a non-linear behavior during the research-entrepreneurship relationship. Phase 1,2,3 and 4 have a negative cash flow until the process reaches the phase 5 when it is possible to consolidate a new start-up company.

In phase 1, the instruction method has to address definition of the medical problem through basic research. For instance, cardiovascular diseases, diabetes and hypertension are good examples where students easily can find different real problems to solve as a manner to understand how R&D works. Phase 2 is more complex since students have to learn how to develop laboratory techniques in order to prove the validity of any instrument concept, i.e. the solution's proposal has to be clinically validated to assure the medical impact. It should be clear for students that if there is no such evidence then phases 3, 4 and 5 do not have any chance of successfully obtaining financial support (cash flow) through entrepreneurship. Thus, the hard part during the teaching process is to explain that the level of innovation depends on how strong the medical evidence is, i.e, prototyping and pre-commercial (alpha and beta testing) difficulties are the phases in which the entrepreneurs have to provide research financing to overcome the "valley of death". Students have to be aware that the final goal is to launch a new start-up company or a technology transfer process as the correct engineering reward for so many efforts.

D. The teaching method

The proposal for the teaching method is to bring to the classroom the picture of what is needed to create the fundamentals of an innovation process. The whole idea consists to point out the following issues:

(a) In addition to the academic interest there is a technology transfer process during the teaching of the course. In order to get this point across, the student's motivation is necessary.

(b) Detection and definition of the right medical problem is the key to determine the course's complexity. This complexity can be variable, starting with the measurement theory fundamentals and optionally extending the method up to include experimental design and the information on how to perform "alpha and beta" testing protocols.

(c) Detection of "bottle necks" as constraints is an important part of the reality that student's should learn sooner o later as BME professionals. Constraint examples, like project budget limitation or finding solutions using only original equipment manufacture (OEM) technology to speed up the construction phase of the results, are the challenging parts of this method.

(d) Finally, the last but not the least important issue is how to teach students that the right solution is not merely based in using the state of the art. On the contrary, students should learn that any solution is balanced by the medical impact and the cost-benefit it generates, i.e. the goal in an innovation process is always obscured by the technology itself, mainly when students look for the most complex solution instead the simplest one. An extension of this methodology may include instruction for patenting and how to design instruments according to norm compliance.

Nevertheless, it is important to emphasize medical instrumentation fundamentals constantly in the first part of this method, not only during the proper definition of the medical problem but also to differentiate "the measurement process from the medical instrument". We believe that this different approach will facilitate the teaching method, particularly when students can distinguish that the "measurement process" is focused virtually towards the appropriate measurand definition. While the "medical instrument" is just focusing on the hardware that the measurand must contain in order to take medical decisions. This new approach is under development but authors think it is easy for students to figure out the concept when they start studying the background of different medical variables (electrophysiological, biochemistry, physics, etc,) with the idea in mind to find new ones (e.g. signals) that can be provide new solutions in the medical instrumentation field, mainly when they apply an innovation process to validate their efficacy and security to take medical decisions.

E. The syllabus strategy

In organizing a syllabus, the authors asked themselves some important questions. For example, which parts of the classical textbooks were appropriate for this different instruction method and what phases in the innovation process need more attention, and therefore classroom-time, than others? How could it be possible to organize the academic material to create both a rhythm and a routine that could be applied to any given week or any given session of study? Does the syllabus really allow sufficient time to engage students in more production-based activities, such as projects and task-based learning? If we were to test the students on this material, how can we assure that the teaching process really provides new knowledge and reflection? Was the instruction process organized in such a way that new and different professors could at glance get a quick overview of what is necessary to enhance or preserve this new teaching approach? In answering these sorts of questions and then sitting down to the task of organizing this material, the challenging nature of syllabus design became much more apparent but very challenging

III. Results

E. Syllabus design

Courses in the Universidad Autónoma Metroplitana have to be taught in trimesters which are 11 weeks long. Specifically, medical instrumentation courses must include 4.5 hours of theory plus 3 hours of laboratory practice for groups of 20 students. The present results are derived from a pilot study where the aforementioned concepts were implemented. The normal course for incorporation of this approach into the regular curriculum is to evaluate these results and to present them to the Biomedical Engineering Undergraduate studies committee who will decide if these changes are incorporated to the curriculum through a vote in the Academic Council of the University.

The result of applying this new teaching methodology was reflected in the objectives of the following syllabus:

1. To identify and to characterize measurement processes. The model of random variable was applied to analyze static measurements. Glucose and blood pressure measurements were used as examples. Mesurands were identified as a consequence of the measurement processes where the medical impact was analyzed according to their error figures with the capability to implement medical decision making for diagnosis and treatment of diabetes and hypertension.

2. To identify and to define innovation processes, emphasis was put on (a) market segmentation definition, (b) design of a commercialization model and (c) identification and definition of the concept for a competitive advantage. Examples of different measurement processes were used like the use of new technologies (D2H2, telemedicine, etc) for the medical impact in the health care delivery system costs.

3. To model medical instrument requirements in relation to the measurement process. Medical instrument modeling by static characteristics was defined. Concepts as precision, accuracy, resolution and bias were defined. The central limit theorem was the tool to estimate medical instrumentation performance when measurands were considered Gaussians. Examples of instrument designs using OEM technology allowed fusing the model for medical instrumentation. The key issue was to introduce simple innovation processes as laboratory experiments. Here, the emphasis was on how to validate the engineering concept as it was explained in phase 2 during an innovation process as shown in Figure 1.

4. To Identify and to evaluate medical instruments through their dynamic characteristics. Laplace modeling was used to characterize the instrument's frequency response. Simulink (Mathworks Inc) was used as a tool to show specific simulation examples.

The gas exchange measurement was selected as a medical problem. Thermistors to measure the tidal volume were suggested as laboratory practice. One idea was to measure the instant inspired and expired flows directly in the nasal cavities in order to overcome the use of the half or full masks for this type of medical problem. The medical impact was discovered by the students when they knew different applications of the gas exchange measurement (indirect calorimetry, exercise assessment, anesthesia, etc) defending the hypothesis that a simple Wheastone-thermistor based instrument was a good solution to get rid of masks for the benefit and comfort of the patient.

5. To learn how to use engineering documentation and statistical analysis. The concept of logbook was emphasized during student's laboratory development of electronics designs. The Bland-Altman method was the tool for statistical analysis when the students wanted to compare their designs with gold standard instrumentation in order to prove the validity of their instrument design. All this was instructed emphasizing the innovation process to the students during the concept validation and the prototyping phases (phases 2 and phase 3).

In Fig. 2, a Bland-Altman analysis is shown when a student was testing his engineering concept. The student's motivation showed up when he could prove through simple and feasible projects the route toward the generation of a possible competitive advantage, despite the fact that he realized he was at the beginning of a real innovation process and had many challenging theoretical concepts with high complexity in front of him. Finally students handed out a laboratory report using their logbook information and using the typical article format.

The result was that only 3 students dropped out of the course, one failed and the rest of them obtained B^{++} in average. This outcome was gratifying because throughout the years, the typical student's grade in this type of courses has been C^{+} with a failure rate of 30%, regardless of the teacher in charge of the course.

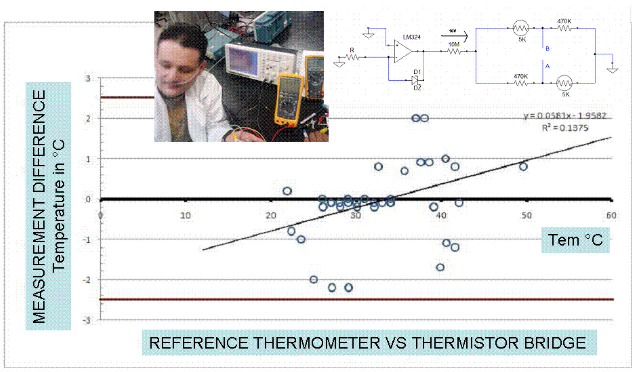

Fig 2. Bland-Altman analysis is shown. The medical instrument was a Wheatstone bridge with thermistors. This simple instrument was applied to measure the tidal volume directly to the nasal cavities.

IV. Discussion and Conclusions

The result of applying this syllabus for teaching medical instrumentation was positive since the majority of the 20 students passed the course with excellent grades (B^{++} of average). Each theme in the syllabus was supported with theoretical and practical laboratory exercises, always with the idea in mind to teach students how to find different solutions using creativity and open mindedness.

The idea to divide the measurement process from the medical instrument concept worked positively. Students discovered the concept of mesurand as the way to define correctly the static and dynamic characteristics of any medical instrument. This concept agreed with the ultimate goal of answering the question of how to enhance or to create more capability for medical decision-making.

The result for this teaching method was not only increasing the student's academic performance but also represented a chance of transforming what began as university project into a possible industrial product with possible benefits for the students. Therefore the hypothesis was proved in the sense that students were more eager to participate and more motivated to study when they discovered the clear retribution to their academic effort in the form of the technology transfer or the possibility to create a start-up company.

The authors learned from this experience that the concept of innovation process helps to define academic goals. Even if it was understood that the main problem for the syllabus design was not how to teach technology issues, it seems that the real challenge was how to educate students to distinguish "nails from hammers" in the ample BME field.

Finally, it is worth to notice that students had severe difficulties in trying to detect medical problems and understand how to generate techniques in order to evaluate the medical impact during the proof of the engineering concept. This is one of several issues that need to be answered to improve the syllabus design together with the teaching methodology.

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