AC 2011-130: MULTI-DIMENSIONAL TELE-HEALTHCARE ENGINEERING UNDERGRADUATE EDUCATION VIA BUILDING-BLOCK-BASED MEDICAL SENSOR LABS

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Multi-Dimensional Tele-healthcare Engineering Undergraduate Education via Building-Block-based Medical Sensor Labs

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Abstract [1] – The entire world is facing healthcare challenges. Human society is in critical need of trained tele-healthcare engineers due to the fast expanding bioengineering industries. In a project (sponsored by U.S. National Science Foundation), we are developing a new course called ECE 493 Tele-healthcare Computing. This paper reports our lab design and teaching experiences. Especially we will discuss our educational development of medical networks and bio-signal processing. We have designed three class labs on ECG sensor and ECG signal processing. Those class labs are developed from a building-block approach. When we offer the lectures to students, we have used a multi-dimensional approach: Dimension-1: Multi-student-level adaptive materials: To meet different schools' course setup requirements, we design basic, intermediate and advanced labs for different levels of undergraduate students. Dimension-2: Medical-application-driven, practical learning: Engineering students show much greater enthusiasm to materials that are closely connected to their lives (i.e. application-driven learning) than pure theoretical lab topics (such as writing a program to verify an algorithm). Dimension-3: Multi-solution-based, creative engineering learning: We propose to use level-to-level question-based, non-instructional lab style to motivate students to seek for solutions from out-of-classroom materials such as web resources. And we will make flexible grading policy to encourage students' out-of-box thinking and creative engineering designs.

Index Words – Tele-healthcare engineering, undergraduate education, Building Blocks, Labs, embedded system

1. Introduction

Healthcare has become a top priority in many countries. Using the U.S. as an example, U.S. healthcare spending was over $2.47 trillion in 2009 and accounted for 17.3% of the nation's Gross Domestic Product (GDP) [1]. One of the most efficient ways to reduce healthcare cost is to reduce in-person or in-hospital medical visits through the tele-Healthcare systems. Tele-healthcare for remote patient monitoring and diagnosis would largely benefit our society (1) by enhancing accessibility to care for underserved populations (such as in rural/remote areas), (2) by containing cost inflation as a result of providing appropriate care to patients in their homes, and (3) by improving quality as a result of providing coordinated and continuous care for patients and highly effective tools for decision support. Especially, tele-healthcare system plays an important role when we face deadly viruses today. By May of 2009 the Swineflu virus has spread from Mexico to over 40 countries. Without good control, its threat could be as threatening as the epidemic flu that occurred in Spain in 1919, killing millions of people.

Although Tele-Healthcare Engineering (THE) is such an important field, unfortunately most engineering schools do not have systematic undergraduate education materials on its hardware/software design. One of the reasons is due to the challenge of developing teaching materials in such a multi-disciplinary field. As shown in Fig.1, tele-healthcare crosses 3 fields: (1) *Healthcare principles*: the medical principles need to be known first before a practical medical engineering design begins. For instance, how do we know a heart-beat signal pattern is abnormal? (2) *Computer Networking*: how does a wireless network remotely transmit the sensed medical data back to a hospital? (3) *Embedded System*: how do we design tiny medical sensors (with hardware / software) to collect medical data?

Note that there are significant differences between THE and general bio-engineering fields: (1) THE emphasizes the enhancement of patients' medical care by using contemporary ECE hardware /software design. However, bio-engineering is a broad discipline, and in most cases it emphasizes the biological instrumental studies such as DNA analysis, bio-chemical nano-particles control, medical

[1] This project is supported by United States National Science Foundation (NSF) (DUE#0941020). Any materials presented here do not necessarily represent US NSF's opinions.

instruments /devices, and others. (2) THE is based on the advanced wireless networking and medical micro-sensor designs (Fig.1) for remote medical diagnosis. But bio-engineering applies engineering principles to the full spectrum of living systems. (3) Bio-engineering needs a separate department with complete curriculum. However, our THE materials could be easily embedded into ECE or other majors. This gives many schools great flexibility and convenience for fast training of tele-healthcare workforces.

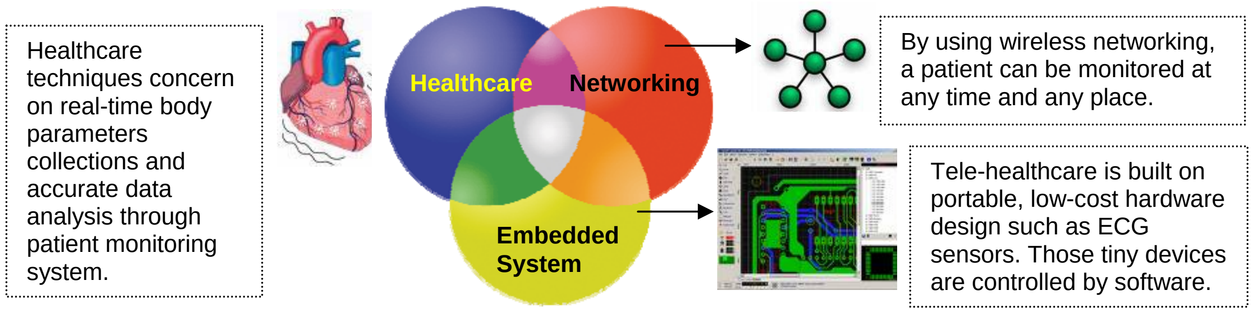


Fig.1 Tele-Healthcare Engineering is an emergent multi-disciplinary field

In a project supported by U.S. NSF (National Science Foundation), we aim to develop a series of lectures and labs for undergraduate students on THE. Our development includes two innovative approaches: (1) *Building-block development style:* Inspired by kids' *building blocks* that could be assembled into an object however with good *modularity* (i.e. the building blocks can be easily reshuffled and assembled into different smaller objects), we are developing five project-labs trees (including cardiac monitoring, mental health, sensor/RFID integration, medical security, and long-distance medical transmission). Those 5 project-lab trees are independent, i.e. there are no time order and context requirements among them. Therefore, each project can be used for a senior project class or in different engineering courses (such as real-time systems, circuit /digital design, wireless communications, etc.). (2) *Multi-Dimensional Learning:* We propose to use 3-dimensional pedagogy to develop and teach tele-healthcare engineering knowledge: Dimension-1: Multi-student-level adaptive materials*:* To meet different schools' course setup requirements, we design *basic, intermediate and advanced* labs for different levels of *undergraduate* students. Dimension-2: Medical-application-driven, practical learning: Engineering students show much greater enthusiasm to materials that are closely connected to their lives (i.e. application-driven learning) than pure theoretical lab topics (such as writing a program to verify an algorithm). Dimension-3: Multi-solution-based, creative engineering learning: We propose to use *level-to-level question-based, non-instructional lab style* to motivate students to seek for solutions from out-of-classroom materials such as web resources. Flexible grading policy will be made in order to encourage students' out-of-box thinking and creative engineering designs.

In the rest of this paper, we will first briefly introduce other related works on THE undergraduate education in section 2. Then we will introduce our lab development strategy based on a building block approach in section 3. In section 4 we will discuss our multi-dimensional THE teaching methodology. Section 5 has learning data from our Fall 2010 teaching class. Finally, section 6 concludes the paper.

2. Related works

Tele-healthcare has attracted significant research activities since 1990s. Part of the reasons is that the continuously increasing medical labor fee necessitates an automated medical management via Internet and computer technologies. Most of tele-healthcare research focuses on low-cost medical data collections. For example, CardioNet is the first provider of mobile cardiac outpatient telemetry (MCOT) service in the USA for continuous monitoring of a patient's ECG and heartbeat [2]. A combined hardware and software platform, known as CodeBlue [3], provides protocols for device discovery and multi-hop routing, as well as a simple medical data query interface for real-time patient monitoring. Other examples of sensor-based medical monitoring systems are SMART [4] and WiiSARD [5]. Unfortunately, there are very few activities that transform tele-healthcare research results into undergraduate teaching. We are also not aware of any tele-healthcare educational developments in previous NSF DUE projects. No appropriate undergraduate textbooks or course materials are available in this field.

3. Class Labs Development: A Building Block Approach

While most of the previous educational activities aim to develop courses with an emphasis of in-order materials organization (i.e. most of the course topics are strongly related and cannot be taught out of the order), our tele-healthcare course / lab design adopts a novel style, called building-block-based tree design (see Fig.2). We are developing the following project-lab trees and topic-subject trees:

(1) Five Project-lab trees: As shown in Fig.2, inspired by kids' building blocks that could be assembled into a big object however with good modularity (i.e., the building blocks can be easily reshuffled and assembled into different smaller objects), we develop 5 project-lab trees with the following 5 topics: cardiac monitoring, mental health, sensor + RFID integration, medical security, and long-distance medical transmission. Those 5 projects are independent, i.e. there are no strict time order and context requirements among them. Since each project does not rely on others, each of them can be used for a senior project class or different engineering courses (such as real-time systems, circuit /digital design, wireless communications, etc.). Following the project-lab tree architecture (Fig.2), each project consists of a series of small labs. Those labs also have good modularity, and can be used for hands-on experiments in other courses. Some of the labs can be easily re-shaped into mini-projects for freshman seminar course labs. Later on we will show a few examples to illustrate this point.

(2) Ten topic-subject trees: We are also developing a complete course, called Tele-healthcare Engineering Design (TED), which consists of 10 TED topic-subject trees on medical data processing, mobile health protocols, tele-medicine security, and other topics. Each topic is decomposed into a few small subjects. If one does not want to offer the entire TED course, partial subjects can be easily extracted and used in other courses (see Fig.2 bottom).

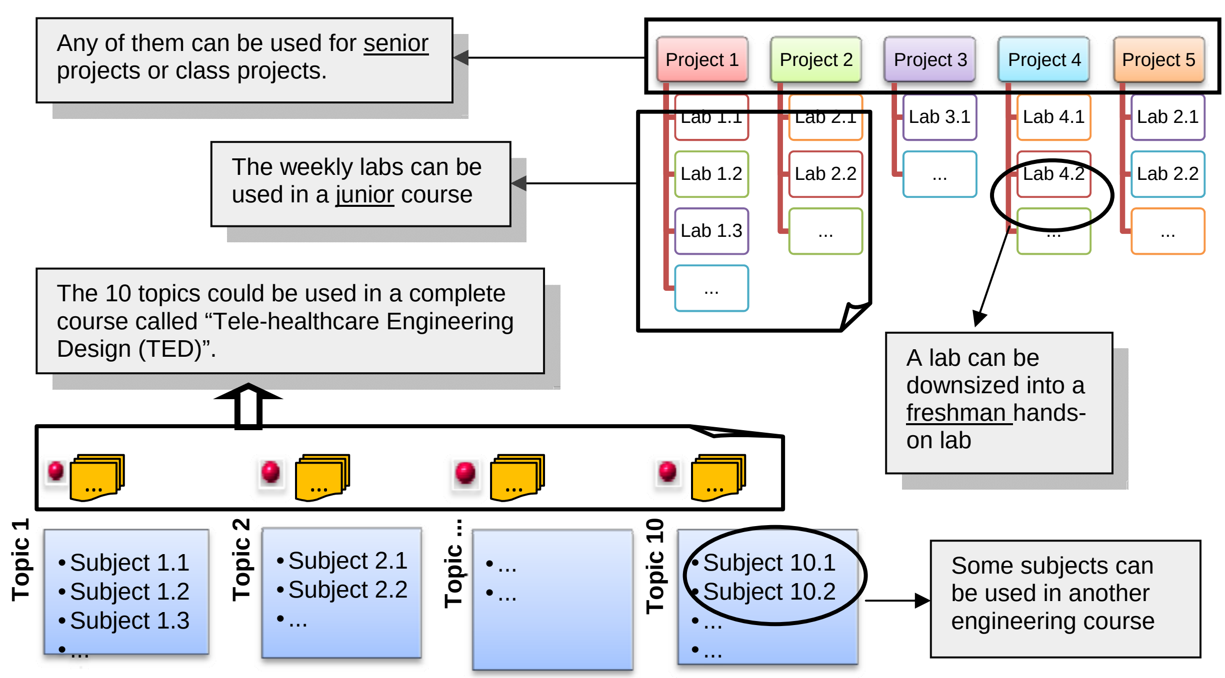


Fig.2 Building-Block Approach to Tele-healthcare Engineering Education

In the following discussion, we will first provide a brief example on the building-block concept. Then we will introduce a more detailed example on a class project called ECG-based patient monitoring

Building-block style example 1: *Project-lab tree #5 - Medical Security*: The protection of patients' data during remote wireless transmission is important. This project can be decomposed into the following three labs: Lab 5.1 – Use Skipjack-based cipher to encrypt /decrypt ECG data between a sensor and a PC. Lab 5.2 – Use one-way hash function to authenticate the source of a received SpO2 value. Lab 5.3 - Use NTRU-based algorithms to reduce the authentication time and memory space.

The above 3 labs have the following features: (1) Independent design: any of them can be used independently without relying on others. Instructors can determine the teaching order between them. (2) Downsizing to freshman seminar projects: Lab 5.2 just uses hash function. It can be further simplified as follows: the instructor provides hash function codes. Student clicks the button in the Windows OS to see what it looks like when a data is encrypted. This can give freshmen an intuition of data security. (3) Upgrade to senior project: since the 3 labs solve different security aspects (confidentiality, authentication, and low-overhead network security), we could require that students design a senior project with all the three modules together based on security math models. They should demo the security performance under different network attacks such as data falsification and network routing misleading attacks.

Example 2: Here we provide a more detailed example on Patient Monitoring. In Fall 2010 we taught a course called "Special Topics: Sensor Networks and Biomedicine Applications". A class project called "Patient Monitoring" was assigned to the entire class. Based on the building block approach, it was decomposed into three class labs (see Fig.3). Each lab was conducted by 4 students in 6 weeks. In the following we will report the students' learning outcomes from such a project-labs tree style.

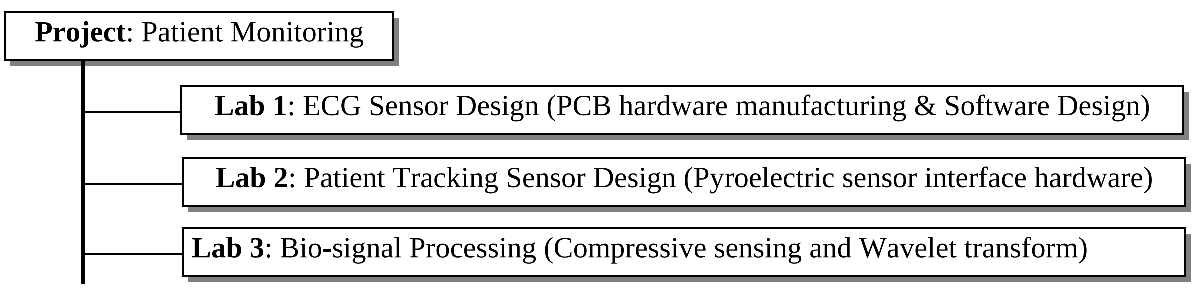


Fig.3 Project-labs tree: Patient Monitoring via Medical Sensors

Student outcomes: The students' learning outcomes were satisfactory. First, they used PCBExpress to design a two-layer PCB board for heart beat monitoring (see Fig.4 left).

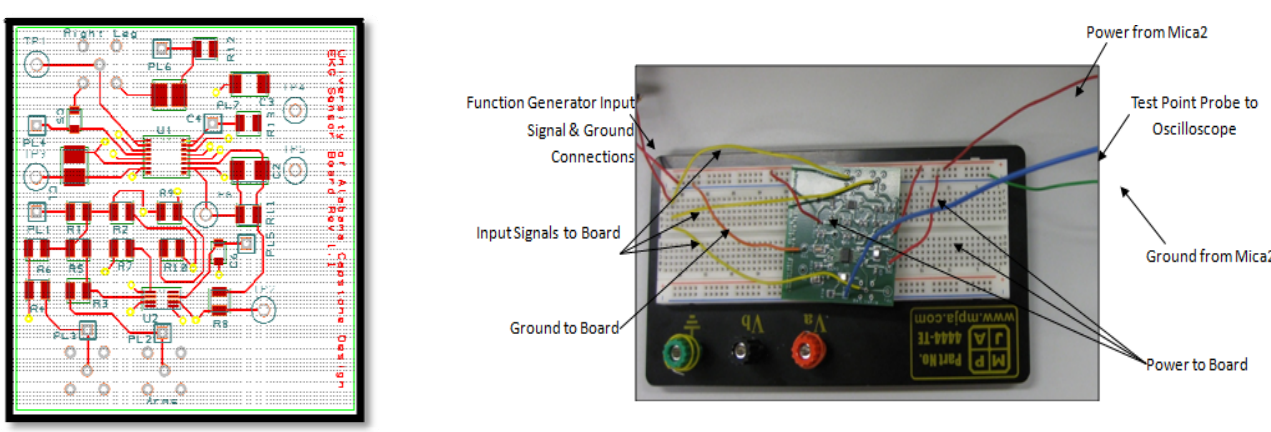


Fig.4 (Left) Student designed ECG board; (Right) Student tested ECG board

More importantly, the students have learned how to test the designed PCB board via signal generators (Fig.4 right). They have verified that the output signal in a 100-meter RF mote is the same as the original sent RF signals. The following was from their lab report (Fig.5):

> **A. Purpose:** To verify expected operation of the analog sensor at specific points and the final output with low frequency inputs; these results may be compared to the strictly simulation results in the previous sections to give approximate expected values and behaviors. Low frequency tests were performed in preparation for integration testing because the Mica2 mote requires low frequency signals for adequate sampling and reconstruction.
>
> **B. Equipment:**
>
> (1) Two agilent function generators with one probe per generator
> (2) One tektronix oscilloscope with three channels and one probe per channel
> (3) One Analog Sensor PCB
> (4) One Mica2 mote with attached DAQ
> (5) Breadboard and assorted wires

Fig.5 Students' lab report (sample)

4. Teaching Approach: Multi-Dimensional Style

Another novelty of our development is to use a *3-dimentional* pedagogy to achieve two goals: (1) Efficient materials delivery: the materials are developed and delivered with different styles (such as freshmen seminar labs, senior projects, on-line learning, etc.) based on *Dimension 1 – multi-student-level adaptive materials.* (2) Enhancing students' motivations: To motivate students to learn engineering, we use realistic medical applications (*Dimension 2*) to build each lab. Moreover, we use *Humanities*' learning style to encourage innovative learning (*Dimension 3*), i.e., allowing students to create multiple solutions to an engineering problem.

4.1 Dimension 1: Adapt to students' levels

To meet different schools' course setup requirements, we design basic, intermediate and advanced labs for different levels of undergraduate students. The basic-level labs can be used for the freshman seminar or some ECE introductory courses to attract freshmen's interests to engineering majors. In the last a few years, we have struggled to maintain the freshmen in engineering major. If we put a few interesting tele-healthcare mini-labs in freshmen seminar course, we could make them enjoy ECE major. The intermediate-level labs are suitable to junior-level students. And the advanced labs can be used for senior-level courses. During our lab design, we mainly target the intermediate level, and extract some simple steps into basic labs. By adding research-oriented tasks, we can shape an intermediate lab to an advanced one. Here we provide a lab design example based on the hardware devices shown in Fig.6:

Lab 1: Medical Sensor / RFID Security. Based on a typical healthcare scenario, the students need to protect patients' privacy through RFID (Fig.6 (b)) communication encryption and sensor-to-sensor (Fig.6 (a)) routing confidentiality. First, students need to integrate a RFID reader in the RF sensor; then Low-overhead key management scheme will be designed to distribute security keys among sensors. Extend to *Advanced*-level lab: The RFID security scheme will be integrated with multi-tag collision avoidance algorithms.

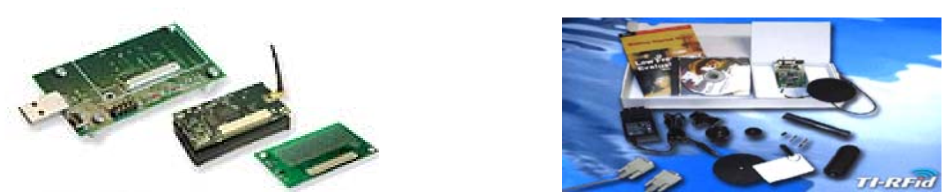


Fig.6 (a) Crossbow Wireless Sensors (b) RFID Evaluation Kit (Texas Instruments)

4.2 Dimension 2: Application-Oriented Lab Development

Engineering students show much greater enthusiasm to labs /projects that are closely connected to their lives (i.e. application-driven design) than pure theoretical lab topics (such as writing a program to verify an algorithm). Therefore, we have set up a typical tele-healthcare application scenario (Fig.7) that is used to develop a series of patient monitoring labs through an integrated RFID (Radio Frequency Identification) / sensor system. The RFID can be used to trace the patient's movement and to tell the type of medicine to be taken. The medical sensors can detect abnormal body parameters.

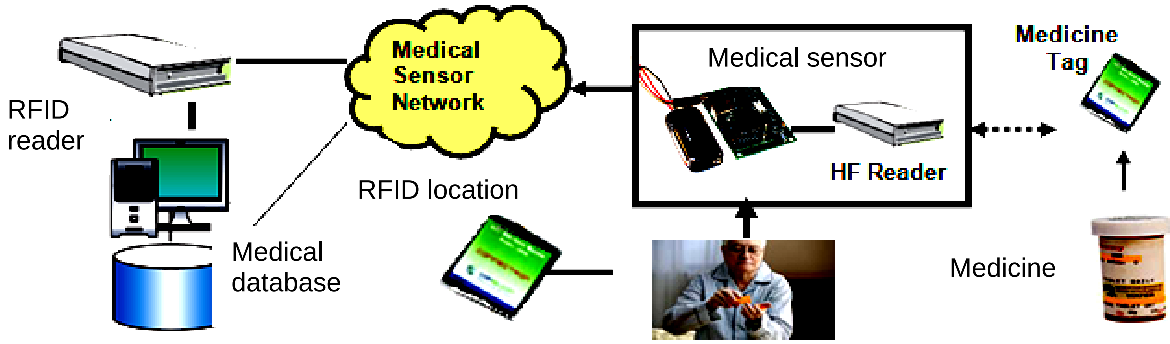


Fig.7 Tele-healthcare lab setup

4.3 Dimension 3: Encourage innovative engineering design

A NSF-sponsored research project (called "The Galileo Project") by Dr. Kazerounian [6] has shown some valuable findings on higher education: our students (especially in engineering majors) still have lots of room for creative improvement. Unfortunately, most of our engineering education approaches do not encourage students to keep an open mind when viewing a problem. Perhaps engineering students think that their assigned problems are different from Humanities majors, that is, assignments usually have a known solution, and students are expected to recognize and regurgitate rather than use learned tools to draw their own unique conclusions. Although this is sufficient for training a capable workforce, it is not effective for developing innovative thinkers. Our TED labs and other assignment development follow an important principle to encourage innovative tele-healthcare engineering learning:

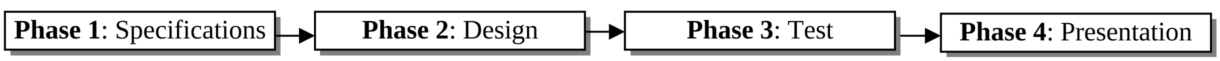
Principle: Leaving ambiguity and encouraging the search for multiple answers: The idea of staying in an open-ended state of thought for as long as possible seemed foreign to most engineers. One reason is that they are usually given unique, fixed solutions and have little space to use creativity. This development takes different approach: there are multiple solutions to the same assignment goal. For instance, we design a medical data mining assignment. We require that the students extract heart beat patterns with bounded extraction latency. However, we do not provide a straightforward, unique answer to such a goal. Instead, the students are encouraged to learn pattern recognition algorithms through multiple ways: web research, digital library, asking professors who teach this course, etc. The instructors organize team discussions to help students get through each possible solution.

How do we enable students' innovative learning in the tele-healthcare experiments? Here we use an example to illustrate our concrete implementation. An important topic is on *patients' sensor network localization*, which finds out a patient's coordination (position) (x,y) via sensor network localization technology. In traditional instructional learning, most schools provide students some GPS receivers to keep track of sensors' locations. Or they provide students *step-to-step instructional procedure* that students should strictly follow in order to generate desired results. Due to strict deadlines and unique solution space, students are not given enough time to back-burn the ideas and come up with innovative solutions. In our proposed innovative learning, to encourage students to generate *creative* engineering design, our lab requirements do not specify unique solutions. Instead, we provide a series of directions for students' imaginations. For instance, we point out "GPS brings high cost for tiny sensors due to expensive satellite communication, what about using neighboring sensors to estimate the patient's location?" → "New issue: If using other sensors, should we use radios or sound? Radio is faster than sound. But slow sound propagation may make it easier to measure early-late difference…" → "If using sound, what math model should be used to calculate triangle positions to locate a sensor?"

The above level-to-level question-based, non-instructional lab style motivates students to seek for solutions from out-of-classroom materials such as web research papers. To encourage out-of-box thinking and multi-solution designs, we will use special grading schemes such as the score of innovation. We will put more focus on learning journey grading instead of just looking at the final score.

5. Learning Data and Findings

In this section, we will report some student learning data from our previous teaching. In Fall 2010, we developed three THE labs in our ECE course (ECE 493 Sensor Networks). The students were divided into 3 groups. There was a leader in each group who was responsible for regular group meetings, monitoring weekly progress and reporting to the instructor. Fig.8 shows student grades distribution in different lab phases. As we can see, through such a *specifications-design-test-presentation* process, students have gained a comprehensive understanding of THE engineering design procedure.



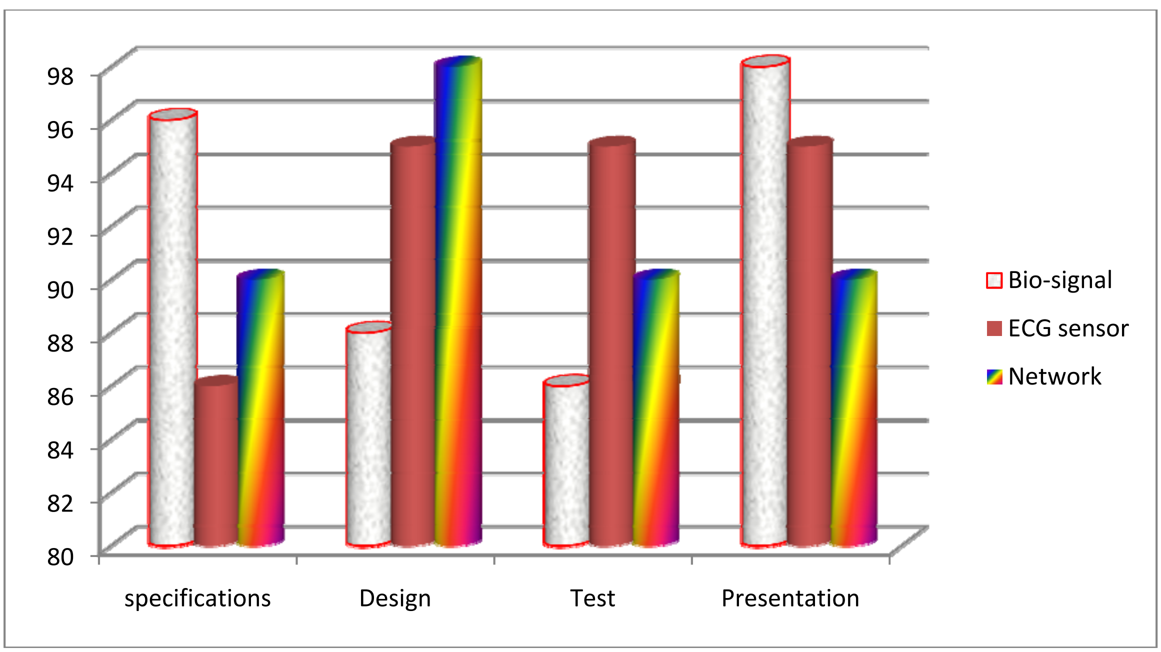


Fig.8 Students learning results from THE lab activities

As we can see from the above data, in Phase I (specifications), the bio-signal processing group has the highest score while ECG sensor hardware design has the lowest one. This is partially because that hardware design needs a complete understanding of PCB layers, circuit parts (amplifiers, filters, etc.), analog-digital board interface, etc. While bio-signal processing has clear input/output requirements, which makes design specifications relatively easier to define. When students get to Phase II (design), Fig.8 shows that bio-signal group has a lower performance than the other two groups. This tells us that ECE students need to have a stronger understanding of digital signal processing (DSP). This is also because our department does not require students take DSP as a regular course (currently it is a professional elective). In Phase 3 (Test), the hardware design group has the highest performance. This could be due to the clear sensor test procedure, which only needs to guarantee the consistency between input signals and output ones. In Phase 4 (Presentation) phase, all groups achieved over 90/100 performance. This could be because of our long-term training of presentation skills for junior/senior students. The following table shows some students' course evaluations (based on personal interview or questionnaire).

Group ID	Students' opinions and comments on their lab learning activities
#1 Bio-signal processing	- "The compressive sensing concept is too deep to be understood by senior…" - "I like the wavelet concept. It is similar to Fourier, but much more powerful…" - "ECE should put DSP as a required course instead of PE (professional electives)".
#2 ECG sensor hardware	- "I enjoy PCBExpress software for circuit design. I believe that I could use it after I find a job in a circuit company. I wish we have a PE on PCB…" - "ECG sensor is hard to design, especially instrumentation amplifier and LPF…"
# 3 THE Network (RF)	- "Can we have more lectures on wireless networking? I want to know more." - "Multi-hop programming over TinyOS is very useful to my career, I believe." …

6. Conclusions and Significance

In this article we have systematically introduced our undergraduate lab development strategy on tele-healthcare engineering. The labs mainly include three parts: medical sensor design, medical signal processing, and medical networks. We have proposed a building block style to develop all class labs. To encourage innovative learning, we have proposed a multi-dimensional pedagogy to link learning to realistic THE applications. The student learning data shows the efficiency of the proposed pedagogy.

Significance: The tele-healthcare engineering has large career opportunities due to its significant reduction of national medical labor cost. This project can greatly benefit other schools' engineering education from the following two aspects: (1) Fill the blank of a new engineering field: The *undergraduate* engineering education should always keep up with the latest cutting-edge technologies. Unfortunately, there are very few developments in tele-healthcare education due to lack of instructors with good tele-healthcare knowledge. For the convenience of other faculty members who do not have telemedicine expertise, we re-shape our long-term telemedicine research results into well-organized, multi-depth-level labs / notes. Our materials train an excellent workforce in healthcare hardware / software design. (2) Explore an innovative engineering pedagogy: The conveyance of engineering knowledge could be very challenging due to lack of industrial application environments in campus, as well as the difficulty of exploring students' creativity due to strict engineering design requirements. Our above proposed *3-dimensional* tele-healthcare teaching methodology could motivate *creative* engineering learning because of its emphasis of out-of-box thinking. When we disseminate our tele-healthcare education materials to other schools, we will emphasize the importance of those teaching philosophies.

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