AC 2011-2249: A NEW APPROACH IN TEACHING "MEASUREMENT LABORATORY" COURSES BASED ON TRIZ

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A new approach in teaching
"Measurement Laboratory" courses based on TRIZ

Abstract

This paper presents a novel approach in improvement of a laboratory based course in "Measurement Laboratory". The course is a core curriculum course for all concentrations of the Engineering Technology (ET) program including electrical, mechanical and industrial engineering technology. The instruction is based on both lecture and hands-on laboratory experimental approaches, leading Engineering Technology students to gain skills and experience in industrial/technological real-life setting as well as in developing innovative ideas. Lectures and laboratory activities have been developed using TRIZ principles and methods. This educational strategy promotes creativity among students, develops an innovative environment and also enables them to identify the best optimum design alternative for an engineering problem.

Traditional laboratory instruction offered up to now a general, vague and too broad vision over mostly mechanical measurements, by using LabVIEW as interface between physical set-up and data acquisition system only seldom and as a prepared package delivered to the student (a "black-box" approach). That limited student understanding as well as his/her engagement in developing the experiment and ultimately grasping the methodology of generating an optimal experimental set-up that serves the purpose of the proposed investigation, the various sources of error and error propagation in such experiment. That led also to disconnection between lectured material and laboratory activity.

To overcome these issues, we proposed an integrated lecture/experiment package, where the student is fully involved in creating and analyzing the experiment during laboratory activity, based on his prior knowledge gained from previous courses as well as in class lectures (delivered prior to each lab activity and closely linked to each lab activity). In this way the student has the opportunity of applying what he learned. Students will be introduced to LabVIEW and be required to create and generate VI's (virtual instrument) to collect needed data from physical experiments. For "Measurement Laboratory" course, students are introduced to more appealing measurement methods, based on new techniques rather than based on mature or even outdated techniques that traditionally are taught in class. For example, they will have lab activities based on reaction times statistics measurements using PIC microcontrollers analyzed vs. computer based LabVIEW VI of the same measurement; capturing temperature measurement using a K thermocouple, a microchip family linear active thermistor and LabVIEW VI's (created by the students) to measure and statistically analyze temperature variation. The software and the physical experiment are connected using a NI DAQ 6009 data acquisition board. In this way, the course gains multi- and interdisciplinary character, enabling students to acquire necessary skills in developing their future projects including "Senior Design".

This course will be offered starting Fall of AY 2011-2012. A preliminary format of this course has been taught and assessed during the fall term of this academic year.

Theory of Inventive Problem Solving (TRIZ) developed by Genrich Altschuller is becoming an important theoretical tool in academic and industrial environment around the world and lately in United States. Also, there is a consensus that TRIZ offers a highly effective pathway to instructing students in producing novel solutions to technical problems in a systematic way.

Introduction

Rapid changes in Engineering Technology (ET) area require new and improved strategies in engineering technology education [1, 2]. The general trend of today's ET education is moving rapidly to project based learning. More than ever, the educational approach is leaning towards meeting the demands of industrial world in terms of skills development and degrees offered. ET curricula need to adapt to emerging technologies by enabling students to acquire meaningful and relevant practices. New courses based on novel approaches should be implemented in order to answer the new industrial and technological challenges. Several studies concluded that the "Conceive-Design-Implement-Operate approach is beneficial in terms of improving teaching and learning, motivating students to further their academic progress and faculty to improve their industrial experience and to gain more insight into industry[3]. Laboratory based courses are vital to ET programs, since they are the backbone of skills-building process, ultimately leading towards developing experience-led engineering technology degree [3]. Also laboratory activities developed should become more and more a place where students can and will be creative, where they will be able to develop not only required skills, but also a place where to practice and improve them.

Invention, Innovation, Design, and Product Development are hallmarks of a modern progressive society and are crucial for sustaining our standard of living and industrial competitiveness. We concur with these viewpoints: creative design and invention can be productively taught throughout several courses in ET, but their effective translation and integration into the engineering and technology curricula are sorely lacking. Methods of assessing and quantifying success in this area remain elusive [4] most likely because of the multifaceted, 'open-ended' nature of design and because it is difficult to objectively evaluate the merits of a design at its early stages. One way to lead the students to become creative and innovative in ET is building a systematic approach of the knowledge to be conveyed during class time by combining laboratory activities with a well structured in class lecture.

The paper presents the challenges to develop a course and course/laboratory components to instruct ET students in measurement technology using systematic methods of problem solving and design. During the course the instructor will also provide some important design case studies in the areas of industrial applications of measurement techniques and technology that should prove of wide interest to engineering technology students.

The measurement science and measurement technology has earned its place and role in engineering and engineering technology programs. However, a general concern is about how much degree of depth in each of them is needed to be taught in a course. On one hand is the academic need of teaching students certain basic knowledge necessary as background for further academic endeavors and on the other is the need of enabling students to develop certain skills required by today's industrial requirements which are directly linked to the requirements of an ET graduate to gain successful employment after graduation. [5, 6]

Measurement Laboratory as a course has been developed around both concepts: measurement science and measurement technology: the first is approached as an information gathering and analysis process and the latter ultimately is about the design and use of a measurement system for a particular application with emphasis on the broad aspects of measurement system design. Such an approach should provide a good base for solving most problems[5]. Measurement technology nowadays become more and more connected with the new and rapid developments and challenges of the internet and web communication era, as well as with the growing field of computer and computer-based applications[6]. The "pure mechanical" approach of a measurement laboratory course is considered to be mature and soon to be outdated.

In recent years, TRIZ (Russian acronym for *theory of systematic inventive problem solving*, developed by Genrich Altshuller in 1946) has gained considerable interest for teaching design and technical problem solving skills. TRIZ is becoming prominent around the world in both educational institutions and industry, but apparently has made few inroads in US secondary and higher education, despite its favorable reception in US corporations, its new role in Six Sigma and Lean programs, and the growing number of management consulting firms, conferences, journals and web resources expounding the virtues and applications of TRIZ [7, 8, 9]. The TRIZ methodology will form, at this phase of development of the course, the general structural approach of the learning strategy employed, being tailored and packaged for "Measurement Laboratory" course. The course will feature lectures and readings that will promote critical thinking, and will use empowering strategies to enhance creativity.

If we put together the systematic approach enabled by TRIZ along with laboratory activities strictly linked to recent developments in measurement technology in terms of basic knowledge, measurement techniques and computer-based approach (LabVIEW), we believe that we have a recipe for success for our ET students. The novelty of this approach consists of seamless integration of the two basic components lecture and lab activities, both of them developed based on the systematic approach offered by TRIZ methods.

While the lectures are developed using systematic creation of solutions for specific situations based on well defined and identified principles, the laboratory activities are developed using "game" approaches as a creativity promoter, and critical thinking developer.

TRIZ – method and approach for "Measurement Laboratory" course

TRIZ, the theory of inventive problem solving, is based on the recognition and exploitation of patterns in the inventive process. The same type of problems keep recurring over a diverse range of technologies and the problems are resolved by a relatively small set of inventive principles.

Figure 1 is a highly simplified schematic of the TRIZ process. A problem is framed in terms of previously well-solved problems. Analogous solutions (from disparate fields of technology) are then used as the basis of the problem solution or design[20]. TRIZ is a very practical and effective theory and one of its components used to develop our laboratories is its "game theory" that enables students to create each lab based on the skills and experience gained in previous lab as well as lectures.

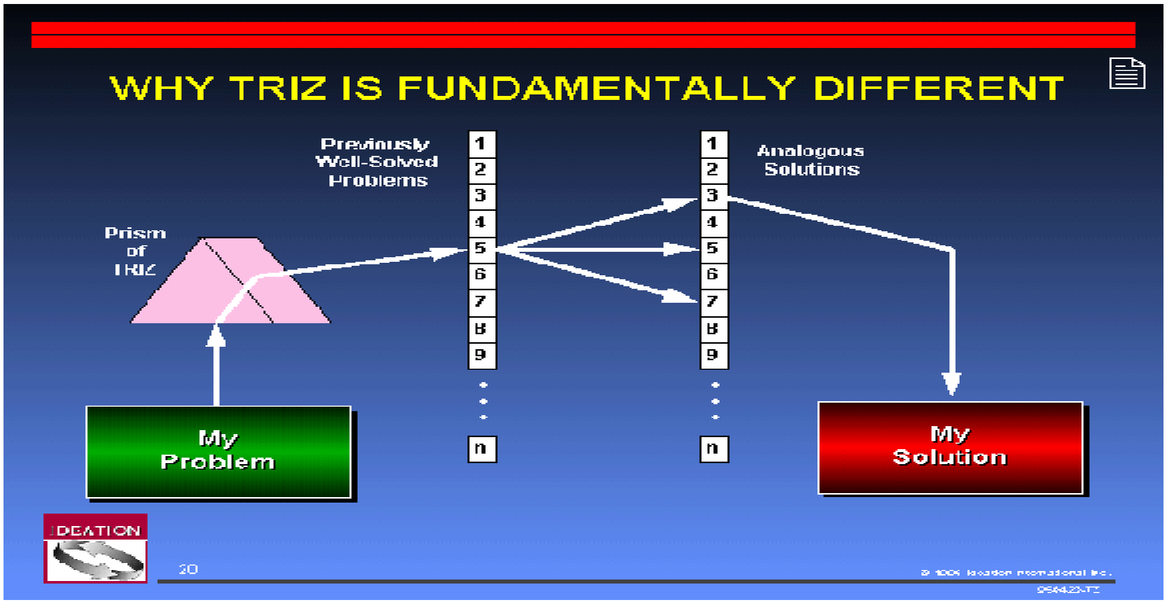

Figure 1: Overview of TRIZ

These principles are used when learning modules have been developed: for instance, choosing the sequence of lectures was based on ability of students to learn by analogies with real-like settings and then apply learnt skills in developing laboratory activities[22, 23, 24]. While conducting laboratories, each student, though following previously created instructions, will be able to come with his unique solution to the problem and also is encouraged to justify his/her solution in the lab report.

Course Development

The entire course is based on giving students the opportunity to identify the problem, to dissect it until it gets to the basic components, to understand the implications of each components as well as the effects of changing each component and then reassembly it to create the solution of the problem using gained knowledge (prior and in class through lectures).

This three-hour credit course is addressed to sophomore level undergraduates students, being a core curriculum course for Mechanical Engineering Technology, Electrical Engineering Technology and Industrial Engineering Technology concentrations. The course has been offered and assessed during the Fall term of this academic year (2010-2011) and will continue to be offered during the subsequent years. Also, a continuous improvement process will be performed based on the evaluation and assessment of each course offered.

The students will follow a sequence of lectures on the topics including basic measurements, statistical analysis, accuracy and precision, measurement tools and instruments, measurement techniques and methodologies, uncertainty analysis. All the lectures will be supported and integrated with laboratory experience. Students are also introduced to LabVIEW as a tool for creating virtual experiments as well as an active and interactive interface between the physical setting and data analysis process.

Upon completion of this course, students should be able to identify and quantify various sources of measurement errors and how they propagate, and be capable of using this knowledge in calculations, to understand the advantages and limitations of the various sensors used in this course. Students will also be able to plan experiments to meet specific engineering accuracy/resolution goals, and they will be able to prepare a high quality engineering reports including presentation of goals, background, results, analysis, and conclusions[25, 26, 27].

The topics covered during this course are presented below:

	Topics
1.	Course intro, Intro to Measurement Systems; Basic Measurements: tools and techniques
2.	Probability and Statistics: Measurement Statistics; Reaction Times
3.	Uncertainty Analysis
4.	Measuring Temperature and Temperature Sensors
5.	Measuring Flow/Pressure and Fluid Sensors
6.	Measuring Rotation and Acceleration
7.	Electronic Measurements: LabVIEW vs. Direct Measurement; Digital vs. Analog Signal Processing

Table 1: Topics of the measurement Laboratory course

One important aspect in Engineering Technology is experiment design – including both the parameters of the actual experiment to be conducted, as well as the specifics of how to go about making the required measurements. In order to provide ET students with valuable experience in experiment design, we have designed a series of exercises to walk students through the design, construction, and implementation of an experiment designed to measure two different types of human reaction times (both with and without anticipation.) These exercises introduce students to the many variables and potential problems involved in designing a typical scientific experiment. In addition, students gain familiarity with typical scientific concepts such as systemic and random error, specification tolerances, and calculation of accuracy of a specific apparatus.

For this series of experiments, students are first asked to come up with an experiment to measure human reaction time. This provides both an opportunity for students to come up with creative methods of measuring a parameter, as well as an opportunity for the instructor to discuss the idea of incomplete specification: I.E. was the original intent to measure human reaction time to an unannounced stimulus, or the accuracy of human reaction time, given the additional cue of a countdown timer? The potential importance of such a distinction could be demonstrated by describing to the students two groups who conducted human reaction time experiments using a microcontroller and LED stimulus: Group A averaged 146ms reaction time, with a standard deviation of 36ms, whereas Group B averaged only 27ms, with a 10ms standard deviation. The initial conclusion would be that something was inherently different between the two groups – and it could then be revealed that Group B had the advantage of a countdown timer.

The reaction-timer apparatus used in our experiments is based on a PIC16F877A microcontroller, using a 20MHz, 50ppm TTL oscillator as a clock source. The microcontroller code is written in assembly, providing cycle-accurate timing between events. This allows reaction times to be measured with accuracy equal to that of the clock source – in this case, 50 parts per million. At 20MHz, the clock cycle time is 50ns; since the PIC16F877A runs at one instruction every four cycles, instructions are executed every 200ns. A timing loop checks for switch closure every 50 instructions, or 10usec. The timing inaccuracy for one loop is therefore on the order of 10usec * 50ppm = 0.5ns. Given a typical reaction time of around 200ms, timing inaccuracy is roughly 200ms * 50ppm = 10us. The LCD output reports times with a resolution of 10us, so the reported time is accurate to roughly the precision shown.

The understanding of such error calculations is a fundamental part of the Measurement Lab course, students derive these results on their own, as part of the lab assignments. Instructors have the option of using this experiment in several different ways, from presenting students with a working timer and asking them to do the error calculations, to having (more advanced) students build and program the devices themselves (perhaps using pre-written delay routines).

During development of the reaction timer devices, it was noted that the variability of the time taken to press the (mechanical) switch may well contribute significantly to the uncertainty in reaction time measurement. Future work on the reaction timer devices will concentrate on development of an optical sensor using a laser diode and photodiode detector, in order to remove the mechanical switch from the loop. Since the response time of photodiodes and laser diodes is on the order of nanoseconds, this should greatly reduce the uncertainty in timing measurement as compared to using a mechanical switch. Students could then compare measurement times using the two methods, and develop conclusions based on comparisons of the relative mean and standard deviation of reaction times measured using both methods.

Additionally, the incorporation of a "countdown timer" series of LEDs is planned, in order to give students experience in measuring human reaction times to both unannounced and anticipated events. Currently, only the unannounced reaction time method is implemented; the system uses a pseudorandom 8-bit number based on the time taken to press the button during the startup sequence to randomize the delay between the start of the experiment and the stimulus signal (LED) being lit. A delay of up to 2,560 milliseconds is added to a fixed initial delay of 2.0 seconds, resulting in a uniformly-distributed, randomized delay time between experiment start and stimulus onset of between 2.0 and 4.56 seconds. For the "countdown" experiment, this would be replaced with a sequence of LEDs being lit at 500ms intervals, ending with the final (stimulus) LED. We anticipate that this approach would result in reaction times with a much smaller mean and SD.

Another experiment used in the Measurement Lab course is a modern take on the traditional Newton's Law of Cooling experiment. Two different temperature-measuring devices – a Type K thermocouple and a DS18B20 Programmable Resolution 1-wire Digital Thermometer – are used to measure temperatures produced by a power resistor, as well as to measure the characteristic heating and cooling curves of these devices.

For the Type K thermocouple, LabVIEW is used to capture raw voltage data using a NI USB-6009 data capture device; these readings are then scaled in the LabVIEW VI to do the voltage-to-temperature conversion.

The output of the DS18B20 Digital Thermometer is factory-calibrated; resolutions of up to 1/16th of a degree C (with a stated accuracy of 0.5 degrees C) [10]. A PIC16F887 microcontroller was programmed to read this temperature data (which is output as a digital signal from the sensor using Maxim's 1-wire protocol) and display it on a LCD display. Since the resolution of the DS18B20 is 1/16th of a degree at the settings used for this experiment, temperature is displayed to a precision of 0.001 degree C. The resolution limitations due to decimal format and inherent sensor resolution, as well as the (much larger) stated 0.5 degree C accuracy range of the devices, are explained to the students.

These experiments allow students to not only gain experience with modern temperature-measurement techniques, but also to better understand Newton's Law of Cooling (including a discussion of time constants in general). In addition, students are provided with another opportunity to familiarize themselves with the various sources of systemic and random experimental error. Due to the digital nature of the sensors used in this experiment, quantization error is also introduced and its effects discussed. Concepts as calibration have been also tested by students during laboratory. Uncertainty analysis has been performed for each laboratory activity.

It should be noted that each student could actually design his/her own unique LabVIEW VI, since each experimental setup is an open-ended design. In this way students gain knowledge about designing a measurement set-up at physical and virtual level that would be answer certain pre-designed requirements. Students will analyze the comparison between physical and virtual settings and they will be able to connect those two in a seamless manner, understanding also the limitations and advantages of both types of settings as well as the importance of remote operation and remote control of measurement systems.

Assessment and evaluation of the project

The "Measurement Laboratory" courses using the topics listed in Table 1 and the methods described in this paper, was offered for the first time in the 2010-2011 academic year. The preliminary assessment of the course has been performed based on the questions listed in table below:

Student Assessment

Q1	Are the new course topics challenging and interesting?
Q2	Have you learn more than expected with the course?
Q3	Are the lab activities useful to you?
Q4	What was the level of "hands-on" experience has been achieved through the laboratory exercises?
Q5	Please, provide an overall evaluation of the course.

Table 2: Questionnaire for the evaluation of the senior project design courses

Since the course was firstly offered in this format this past Fall term (we operate on trimesters of 10 weeks of instruction), only a partial assessment has been performed and was based on "student assessment". At the end of the quarter, all students have been requested to answer (with a five point scale: 1-very poor, 2-poor, 3-satisfactory, 4-good and 5-very good) an anonymous questionnaire as shown in Table 2. According to the results, the new lab-based approach received a 3.7/5.0 rating, comparing with an average rating of 3.4/5.0 for all the courses at our program. The results from the students' feedback have been extremely positive with the regard to the experiments provided during the laboratory sessions as well as the lecture content. The majority of students felt that such projects enhanced their understanding of the theoretical materials and made the course more interesting. Similar surveys were or are planned to be conducted at the end of each quarter of the current and next academic years.

Also, more in-depth evaluation and assessment of this course will be performed starting with the next academic year. The future procedure is described below.

Evaluation of the course and data collection will begin soon after the start of the course. On the first meeting of each course, students will be administered a preliminary assessment test to gauge students' background and preparation for the course. For example, their knowledge of appropriate physics and statistics will be evaluated. Based on the results of the test, students will be divided by groups according to the think-share-report-learn (TSRL) process, which will involve student peer coaching to help each other during the laboratory procedures.

Evaluation evidence will be generated through activities integrated into the natural flow of the project. Both qualitative and quantitative data will be collected to assess program performance: the evaluation first provides a detailed description of the program followed by a focus on three key areas: Program Implementation, Achievement of Program Outcomes, and Program Lessons Learned.

The formative evaluation will provide evidence of the strengths and weaknesses of the proposed course. The preliminary and intermediate analyses made by the students also provide numerous metrics to the instructors, which can be used to monitor the competency and understanding of the students' use and application of measurement techniques. A summative evaluation will assess the quality and impact of this course on overall ET program as well as on students' skills development. Proposed summative evaluation questions include:

- To what extent did participants use what they were taught in their own activities?
- Which topics and techniques were most often (or least often) incorporated?
- To what extent did participants share their recently acquired knowledge and skills with others?
- Did changes occur in the overall perception and behavior of participants?
- What were the obstacles, if any, to the introduction of changes?
- Is the overall course consistent with stated goals and objectives of ET program?

Standard course evaluation forms will ask students to compare their level of competence in areas identified in the course objectives at the end of the course to their level before taking the course. This provides immediate feedback on the success of the course in meeting its objectives. The form will include the Likert-type questions, which assess the students' perception of their confidence, knowledge, and competence.

Outreach Component

Engineering Technology in general, and the Drexel University Goodwin Engineering Technology Program in particular, represent an attractive option for technically-inclined students whose interests and motivations center on practical applications, manufacturing, hands-on problem solving, and intuitive and visual thinking; and for whom the abstract theory and analysis emphasized in traditional engineering courses of study proves to be a disincentive. This type of student is a valuable asset to industry and such students may forego a career path in science and engineering unless options such as Engineering Technology are open to them. Goodwin College has fostered an awareness of the Engineering Technology to regional urban and suburban high schools and community colleges by an aggressive high-school outreach through presentations and demonstration sessions. In European schools (under the TETRIS Program) TRIZ-based problem solving has been very successfully used with secondary school students.

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