Modern Engineering Laboratories That Deliver

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Abstract

Electronic instrumentation and computer data acquisition has revolutionized the experimental laboratory. Universities with limited funding face major challenges in upgrading their laboratories. Industry advisors tell us they expect our engineering graduates to have modern laboratory skills. Many engineering faculty members do not possess the modern skills required to develop and/or teach laboratory curriculums required in the 21st century. This situation has developed over several decades due to universities not giving adequate emphasis and workload credit for developing and teaching labs. The senior level mechanical engineering laboratory curriculum at University of Tennessee at Chattanooga (UTC) has been totally redesigned. The new curriculum is a two-hour senior level course (one-hour lecture plus a three-hour laboratory weekly) that includes both mechanical and thermal laboratory systems along with a five-week student design project. The one-hour lecture component of the course teaches modern engineering experimental concepts required to design, collect, analyze, and interpret experimental results. The three-hour laboratory includes experiments related to refrigeration, heat exchangers, thermal conduction, transient heat transfer, internal combustion engines, combustion and emission controls for boilers, linear vibrations, dynamics balancing of rotating shafts, kinematics of motion for piston-cams, and spring dynamics. The design project is an incubator for developing similar modern lab systems for other programs in the College of Engineering. Some of the new labs are operated ON-LINE using the Internet to demonstrate the full capabilities of modern computer based experimentation. LabVIEW is used for data acquisition, analysis, presentation, and control. The paper will describe (1) new curriculum considerations, (2) modern laboratory features used including running ON-LINE over the Internet, (3) scope and objectives for the new laboratory, (4) laboratory administration, (5) design project benefits, (6) ABET benefits, (7) university benefits, (8) faculty benefits, (9) student responses-outcomes, and (10) general laboratory content with two labs featured with photographs.

Introduction

Most university engineering laboratories have been underfunded and neglected over the past decades. This has resulted from the university not providing adequate workload credit for development and teaching of labs as compared to that given for research [2]. These deficiencies have allowed many of our engineering labs to become obsolete as faculty interest in providing on-going laboratory development and supportive computer related skills has declined [3]. This trend must be reversed as our university industry advisors remind us that they expect our graduates to have skills that can only be learned in a laboratory setting where modern instrumentation and computers interface in performing data acquisition, analysis, control, and presentation [4]. The modern skills required to support new laboratory teaching and development at UTC were acquired through university faculty development grants. The new laboratory costs were shared by the state of Tennessee, UTC's Center for Computer Excellence, University of Chattanooga Foundation, and many industrial sponsors like National Instruments, Tennessee Valley Authority, MicroMotion, Analog Devices, Saturn Corporation, and DuPont.

New Curriculum Considerations

The curriculum revisions required for supporting the new laboratory concept at UTC were not accepted as imperative by some of the faculty even though our experienced graduates and industry representatives insisted that we move ahead with haste in bringing about the changes. Our making the revisions to the mechanical engineering curriculum was made easier as our Dean of Engineering and Computer Science and mechanical engineering area director fully supported the changes.

The older mechanical engineering program at UTC had two senior labs (a 1-hour heat transfer lab that all mechanical engineering students took and a 1-hour energy conversion lab that only thermal mechanical engineering students took). The new (2) semester hour lab course (1-hour of lecture plus one 3-hour lab weekly) is taken by both mechanical and thermal area students. The new lab includes ten mechanical and thermal systems labs and a five-week design project.

Modern Laboratory Features

The older mechanical engineering labs at UTC used no computer data acquisition while the new 2-hour lab has electronic instrumentation, data acquisition, analysis, control, and presentation integrated throughout all lab systems. No new laboratory systems were purchased, as on-hand systems were retrofitted-upgraded with new instrumentation and data acquisition using LabVIEW. The development of the new lab provided a challenging and comprehensive learning experience for the faculty members and engineering staff involved in the overall process.

Scope and Objectives for New Laboratory

The new laboratory was designed with the following objectives [5]: (1) to give the student an opportunity to apply fundamental concepts related to mechanical and energy systems, (2) to familiarize the student with measurement techniques using many "state-of-art" instruments that are encountered in industry, (3) to give the student experience in computer data acquisition, analysis, control, and presentation, (4) to expand the student's computer application skills through use of word processing, spreadsheets, and graphics, (5) to develop the student's oral and written communication skills through oral presentations and technical report writing, and (6) to develop student team coordination skills.

The laboratory experiments consist of three modules (common, thermal, and mechanical) with the common labs being related to thermodynamics, fluid mechanics, and heat transfer that is taken by all mechanical engineering students. The thermal labs cover thermal science curriculum content while the mechanical systems labs contain content that is related to the machine design curriculum. All mechanical engineering graduates are expected to have a general understanding of both mechanical and thermal system areas. The students having completed the new lab will have obtained experiences that will enhance their opportunity to be successful engineers.

The content of each of the lab areas was established to stress the basic fundamentals taught in the mechanical engineering curriculum while demonstrating the unique potential of experimental measurements using computer data acquisition. These considerations provide the opportunity for integration of many forms of instrumentation into a single experiment. The development of additional mechanical design experiments represents a challenge as thermal science systems with extensive electronic instrumentation and data acquisition capabilities are common while mechanical design systems using electronic instrumentation are less common.

Two 3-semester hour courses; Heat Transfer (Engineering 405) and Mechanical Vibrations (Engineering 445) are co-requisite with the new mechanical engineering laboratory course. The lecture portion of the new course covers the general characteristics of instrumentation, electrical measurement systems, statistical error analysis, and computerized data acquisition systems. Homework is assigned, and tests are administered in the lecture portion of the new lab.

A new text entitled "Introduction to Engineering Experimentation" by Anthony J. Wheeler and Ahmad R. Ganji [6] was selected as it provides good coverage of experimental measurement systems with electrical signals, computerized data acquisition systems, and statistics. Most other texts considered were revised editions of older texts that contained less important information related to modern experimental measurement and design.

Laboratory Administration

The new laboratory was developed for fifteen students per class. Five experiments can be conducted *concurrently* each week at five different workstations. Three students are responsible for conducting each experiment. A manager is assigned the role of over-all responsibility for conducting the experiment and submitting the final report for the group. A second student is responsible for theory and procedures, and a third student is responsible for data acquisition, presentation, and analysis. The roles of the students are rotated for each experiment. Group members do the development of the final report jointly with the manager coordinating the effort. The roles of each student will be assigned at least one week prior to the experiment. The lab instructor and group members will meet individually and/or separately to discuss the role each is to play in conducting the assigned experiment. These details must be completed prior to the group arriving to conduct the experiment. This provides for an informed discussion of the details of the experiment by the workstation group during the first phase of the three-hour lab period without the instructor being responsible for total learning during this period. The latter period of the lab period is used to complete the experimental objectives. *Two* instructors divide their time between the five workstations as the different experiments are being conducted.

Formal reports are submitted for about half of the experiments while informal reports are submitted for the others. The reports are due two weeks after the experiment is completed. The student grade is evaluated with the lecture portion counting 30% (10% for homework and 10%

each for the midterm and the final exam), the laboratory portion counting 55% (42% for reports, 5% for oral presentation(s), and 8% instructor's evaluation), and design project 15%.

Design Project Benefits

The five week long design project is typically an incubator for developing similar modern lab systems for other programs in the College of Engineering and Computer Science at UTC. Fluid mechanics and strength of materials lab systems along with other mechanical engineering lab systems have been renovated-upgraded through the student design projects. Generally speaking, graduating student responses show that the design project is most beneficial in that it enables the students to see how their college experience can be used in developing a new product or designing a modern experimental testing program. Students taking the mechanical engineering lab are leaders in their capstone senior design project due to their having the capability to use fundamental engineering analysis tools and develop sophisticated data acquisition, analysis, and presentation systems.

ABET Benefits

The 1997 ABET visit found major deficiencies in UTC Engineering laboratories, along with other considerations. The renovation-upgrading of the Senior Mechanical Engineering Lab along with fluid mechanics, strength of materials, controls, chemical, and environmental laboratories was completed prior to the 2000 visit. With the university having raised the salaries of its professor level faculty and the state of Tennessee having committed to a new building to house the College of Engineering and Computer Science, all such deficiencies were apparently removed. The ABET committee was very impressed with the improvements that had been completed in the short period of time.

University Benefits

A new experimental laboratory can be developed by purchasing new equipment that includes modern computer data acquisition systems with the entire package being purchased from a single supplier who is responsible for its design and construction [7]. This is generally the easiest way to expand an older lab or develop a new lab. But, this procedure does generate many problems that must be addressed with the operation and long-term maintenance of the systems.

An alternate way to develop a new lab is to take older, proven systems and retrofit them with modern electronic measurement and computer data acquisition systems with a faculty member being responsible for the development.

The purchase of a totally new system is typically far more expensive than an older model that had no data acquisition, analysis, control, or presentation capabilities. The large increase in costs is primarily associated with instrumentation and computer hardware and software development. A major portion of the increased cost is related to developmental expenses required to produce small sale volume systems typical of engineering laboratory equipment. The production of a new lab through retrofitting older equipment is less expensive than a turnkey purchase as the developmental costs associated with selection of the new instrumentation and computer data acquisition software are reduced due to faculty performing the tasks. The original UTC purchase costs of the lab systems that were used in the new lab were about $80,000. Another $70,000 was spent in upgrading those labs systems. These fully renovated lab systems would have cost over $600,000 if purchased as turnkey systems from commercial vendors. This represents a saving of 75% when compared to outfitting the new lab with totally new systems purchased at today's cost. Additionally, the upgrading of these lab systems took an equivalent time of two full summer periods for the faculty developer.

Another most important advantage to retrofitting is that the faculty member is involved in developing and operating the new system. The commitment to developing the specifications for selecting the new instrumentation and writing the computer data acquisition applications offers a rewarding learning experience. The faculty members have a greater understanding of the complexities and day-to-day problems that will be faced during the operation of the lab if they have been responsible for renovating the older systems.

The faculty members who were responsible for developing the new laboratory attended a five-day workshop taught by National Instruments. Three days were used in teaching basic LabVIEW programming [8], and two days were used for teaching data acquisition fundamentals [9]. Attending the LabVIEW workshop was most helpful as it provided a jump-start that could not have been obtained readily through use of National Instruments' publications. University faculty developmental grants were used to support travel and workshop expenses.

Faculty Benefits

Faculty members who have been involved in developing and teaching the new lab have received "exceptional" faculty ratings and reduced teaching load due to their association with the ongoing development of the new senior mechanical engineering lab. UTC faculty has shared their laboratory development experiences at regional and national ASEE meetings through paper presentations and full-day workshops related to modern mechanical engineering lab development. The University of Chattanooga Foundation has supported extensive lab development activities during the summer period for lead faculty members.

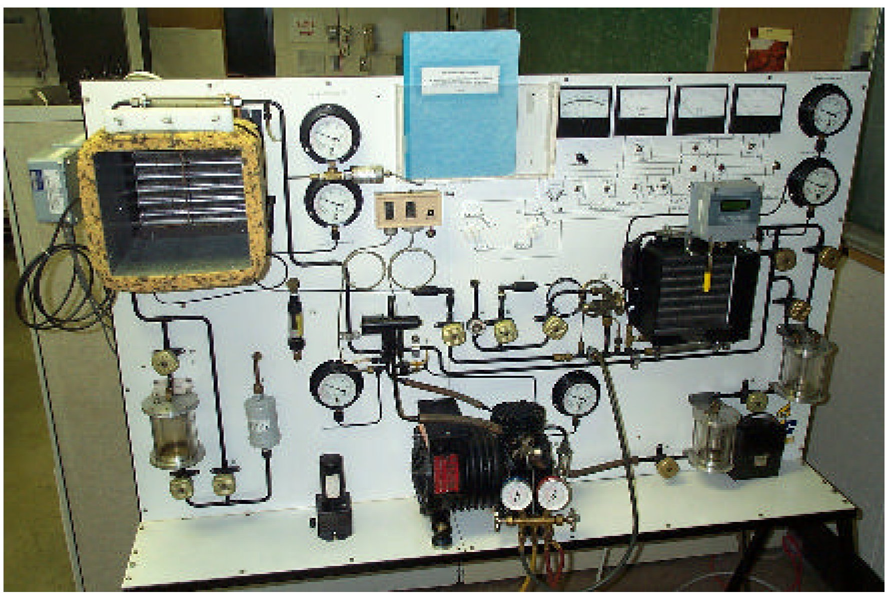
Laboratory Content

The common experiments are Refrigeration Trainer, Heat Conduction, and Heat Exchangers. The thermal experiments are Internal Combustion Engine Mass and Energy Balances, Combustion Products and Emission Controls, and Natural Gas Boiler Study. The mechanical experiments are Stress-Strain Deflection of Beam, Linear Vibrations, Rotational Balancing, and Kinematics of Motion of Piston-Cam. Two of these experiments will be described below to illustrate how instrumentation, fundamental experimentation, and report writing are integrated into each lab.

Refrigeration Trainer

The objectives of the lab are to complete overall energy and mass balances for the heat pump-air conditioning system, to utilize many forms of electronic instrumentation, to introduce LabVIEW data acquisition, analysis, presentation, and to develop spreadsheet analysis skills.

A Model 900 Heat Pump-Air Conditioning Trainer manufactured by Lab Science is used in the experiment. The system as purchased had six Bourdon pressure gages and six type K thermocouples that were used to obtain pressures and temperatures at the discharge of the compressor, the inlet to the condenser, the exit of the condenser, the inlet to the evaporator, the exit to the evaporator, and the inlet to the compressor. Various other instrumentation/controls required to operate the system in both cooling and heating modes are included. The Trainer was retrofitted with two electronic pressure sensors to establish the high and low side pressures, electronic dry bulb-relative humidity sensors on both sides of the condenser and evaporator coils, a hot wire anemometer on the discharge side of the condenser coil, and a turbine flow meter at the exit of the condenser to measure the Freon-12 flow rate.



Renovated Refrigeration Trainer

In addition, the six thermocouples were connected to signal conditioning devices to support data acquisition. A LabVIEW application was developed to analyze and present the experimental data for the modified Trainer.

The students complete an extensive spreadsheet for the experiment with energy balances being performed on the evaporator and condenser using the Freon-12 refrigerant properties and flow rate. An airside energy balance is conducted for the condenser and evaporator using local psychrometric conditions. Traditional coefficients of performance and energy efficiency values are computed for each test. LabVIEW, assuming the Freon-12 refrigerant to be an ideal gas, computes compressor efficiency values. Real Freon-12 fluid properties are used in the spreadsheet program developed by the student to perform a similar computation. Nine tests are run on the system as the airflow rates are set a low, medium, and high for both coils. The results demonstrate how the Trainer's performance is related to airflow capacity over the condenser and evaporator coils. The Trainer is operated in both heating and air conditioning modes. Trainer performance with undercharge and overcharge of refrigerant is also investigated. The results are presented in a formal report developed by the lab group.

Kinematics of Motion for Piston-Cam

The objectives of the laboratory are to investigate the motion of a slider-crank mechanism through displacement, velocity, and acceleration analysis and experimentation, to investigate cam design, to develop LabVIEW and TK SOLVER or MAPLE utilization skills, and to explore technologies required to operate the lab ON-LINE over the Internet.

A 3.5 horsepower Briggs & Stratton engine is used to produce the slider-crank motion while the cam driven exhaust and intake valves are used for cam study. LVDT displacement sensors are connected to the piston and valve with data acquisition, analysis, and presentation being completed by LabVIEW and motion simulation computations being done using TK SOLVER or MAPLE.

Three different engines are used in the lab, one being torn apart so students can have hands-on experiences with each component, a second having cut-away sections removed from the engine block so the student can view each internal component as the engine crank is driven by a crank handle, and the third engine having electronic sensors mounted that provide piston and cam displacement as the engine is driven by an external, variable speed electric motor. LabVIEW computes the velocity and acceleration for the piston and cam motion. The breakdown engine and cut-away engine provide first hand exposure to the "ultimate" mechanical engineering system as an internal combustion engine incorporates all fundamental mechanical engineering design concepts.

Most of the lab time is committed to the hands-on and cutaway engine exploratory learning and introduction to TK SOLVER, with inadequate time left to complete full testing. Therefore, this lab has been put ON-LINE. In utilizing this feature, each student completes testing at different engine speeds outside of the lab experience. The group members share their experimental results. The capability to obtain and analyze experimental data and present the findings over the Internet represents a major challenge that most undergraduate engineering students do not get. This experience provides the student with a background that challenges their capabilities in experimental design and information dissimilation.

Information related to operating this system ON-LINE along with information about other modern laboratory systems can be found at web site: **http://www.Reallabs.net**. Creative Engineering Laboratory System, a company that is building turnkey modern laboratory systems like those described in this paper, maintains this web site.

Kinematics of Motion for Piston-Cam System

Student Responses-Outcomes

Student responses, both verbally and conveyed through senior exit surveys, have provided very positive feedback related to the new laboratory. This past year, students responses conveyed a score 3.8 of 4 when asked how they rate the educational value received in the new senior mechanical engineering lab. Instructors have received four years of very positive feedback from our students who immediately use the lab skills and graduates who have made significant contributions in design of experimental systems in industry. Laboratory and design reports show that the new lab supports ABET Outcomes **b** (demonstrate an ability to design and conduct experiments, as well as to analyze and interpret data), **c** (demonstrate an ability to design a system, component, of process to meet desired needs), and **k** (demonstrate an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice).

Conclusions

The new Senior Mechanical Engineering Lab has met most of its objectives while written and verbal communication outcomes of the lab as always need improvement. The faculty who teach the lab has become adaptive to modern instrumentation and computer data acquisition, and the mechanical engineering students who take the lab are demonstrating improved skills in other senior level course work and related job experiences. Graduates of our mechanical engineering program feel that the new lab offers an excellent educational value. The successes of the new lab should be used in curriculum renovation for other labs in the UTC Engineering Program.

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Biographical

Charles V. Knight received B.S., M.S., and Ph.D. degrees in mechanical engineering from The University of Tennessee at Knoxville. Dr. Knight has been a member of The University of Tennessee at Chattanooga faculty since 1979, having taught at University of Tennessee campuses in Nashville and Knoxville ten years previously. His teaching interests are associated with fluid mechanics and thermal sciences. He completed six years of research for Tennessee Valley Authority associated with combustion and exhaust gas emissions and indoor air quality influences for wood burning heaters and boilers. He served as president of the Chattanooga Section of American Society of Mechanical Engineers in 1990 and chairman of Mechanical Engineering Division in 1986 and 1999 and general program chairman in 1988 for Southeaster Section of American Society for Engineering Education. More recently Dr. Knight has been responsible for mechanical engineering curriculum renovation, lab development, and ABET 2000 assessment at UTC. He is a registered Professional Engineer.