An Undergraduate Instructional Laboratory Model for a Modern Mechanical Engineering Program

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Abstract

Hands-on laboratory skills play a vital role in preparing the next generation of mechanical engineering students to assume successful career paths in the 21st century. Our team reviewed several undergraduate laboratory models at a number of well-recognized undergraduate engineering institutions. When possible, we also sought the feedback of some of these institutions and gathered the lessons learned in their developing undergraduate laboratories. Using the gathered information, we have developed our own model for a set of four mechanical engineering laboratories that we believe will address the needs of a modern mechanical engineering program. Students are required to take three of the four offered labs. The labs begin in the fall semester of the sophomore year and successful students will complete the three required labs by the end of their junior year and can take the 4th lab in their senior year as a technical elective. This paper provides the information on each of the four lab modules, including the experiments covered in each lab and the specific educational objectives sought in each lab.

Introduction

The Petroleum Institute (PI), which was founded in 2001, is supported by a consortium of five major oil companies. These are: Abu Dhabi National Oil Company (ADNOC), British Petroleum (BP), Judco, Shell, and Total. The prime sponsor is ADNOC, providing more than 60% of the funds and having established close working relationship with the PI. ADNOC is a $40B company, owned by and operated in the United Arab Emirates with diverse interests in the oil and gas industry, including various subsidiaries and operating companies in the major business areas of exploration, drilling, production, refining, and gas processing operations, as well as transportation and marketing. The Petroleum Institute is a higher educational institute that trains the workforce for the oil and gas industry, and particularly for the companies involved in the sponsoring consortium. PI offers undergraduate (and soon graduate studies) in the five major engineering fields of chemical, electrical, mechanical, petroleum, and petroleum geosciences engineering. Additional engineering disciplines are expected to be added in the future, in-line with the needs of the sponsoring consortium and the local oil companies. The Petroleum Institute also provides research and continuing education services to its sponsors thus justifying the need for state-of-the-art laboratories at both undergraduate and graduate levels.

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Graduates from the Mechanical Engineering Department at the PI will work for ADNOC and other sponsoring companies as field test engineers, laboratory test engineers, design engineers, development engineers, project management engineers, and research engineers. We must prepare the students with the ability to undertake a variety of engineering tasks in the oil and gas industry. Laboratory and hands-on training has proven as an effective tool in preparing the students with the necessary skills to tackle problems of significance to the industry and field engineering. The past decade has seen an increase in the industry's work load. Engineers should be able to stand the pace to accomplish their work and projects on schedule. In order to increase time-management and efficiency it is recommended to integrate the fundamental theories with the hands-on experience in the laboratory and employ effective project management skills [1-3].

The undergraduate laboratories curriculum at the PI is designed in-line with the needs of our sponsors for well prepared mechanical engineering students for various positions in the oil and gas industry, and the broader energy field in general, with the goal to reduce and minimize the additional training required by the sponsors once graduates enter the work force. The proposed model includes a set of four undergraduate laboratories, mechanical engineering labs I through IV. Lab I introduces basic engineering tools, manufacturing, and machining techniques, followed by lab II which focuses on basic measurement and instrumentation techniques. Lab III involves measurement and instrumentation techniques for measurements in mechanical engineering core subject areas such as thermal-fluid sciences, mechanics and failure analysis, materials science, and automation/control. Lab IV is an advanced measurements lab designed for senior and graduate students with experiments involving advanced subject matters and instrumentation techniques in the major areas of mechanical engineering. The proposed model, while decouples the labs from various courses taught, offers a sequence that accommodates parallel offering of the laboratories with corresponding courses. We believe this helps eliminate the uncertainty associated with various professors teaching the courses involved and the degree they may consider the lab integration in their courses important, hence helping the student better learn the subject mater.

This paper discusses the details of each lab, the experiments involved in each lab, and the outcomes and educational objective sought for each lab.

Descriptions of the Laboratories

Figure 1 depicts the overall curriculum of our mechanical engineering program at the Petroleum Institute. As seen there, the four-year curriculum includes a set of four labs, with the first one offered in the fall semester of the sophomore year and the last one offered as a technical elective course in the senior year. While the first three courses are two credits each, the advanced measurement and instrumentation lab is a three credit technical elective course and is open to senior students as well as graduate students in mechanical engineering. The curriculum itself represents a typical modern mechanical engineering program, which allows for covering of the core subject matters in the sophomore and junior years, with generous amount of credits for technical elective courses of interest to the student in the senior year. The technical electives are offered in the major speciality areas listed at the bottom of the curriculum poster, which include courses in general core subjects, as well as automation and controls, mechanics and materials,

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and thermo-fluids sciences. By taking additional courses in a selected field the student has the opportunity to further focus in each of the three major areas. The four laboratory courses are described in the following sections.

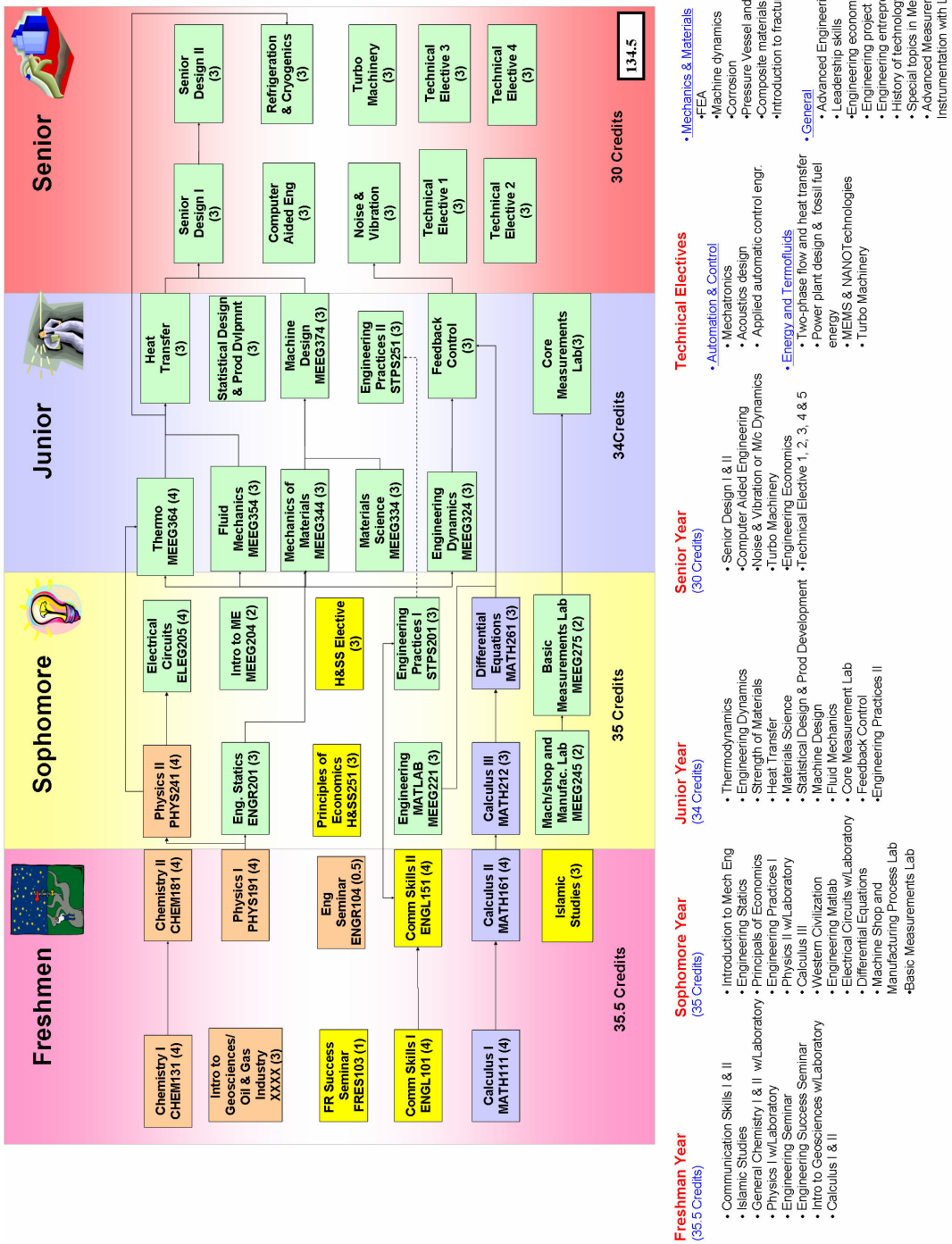

Figure 1. ME curriculum at the Petroleum Institute

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Lab I – Machine Shop and Manufacturing Laboratory

No prerequisite other than sophomore status is required for this laboratory, which is offered in the fall semester of the sophomore year. The topics covered in this laboratory are depicted in figure 2. As seen there, they begin with a module on health, safety and environmental requirements (HSE). Health, safety, and environment (HSE) is one of the most important items in the oil and gas industry, thus highly focused in our laboratories and the Institute as a whole. We have taken measures to ensure good HSE practices in all of our laboratories and particularly in the machine shop. Students are taught the basics involved and the necessary measures to safely operate power equipment and avoid accidents and injuries. Students learn about the care and maintenance of laboratory equipment, especially hand tools and laboratory instruments.

The HSE module in Lab I is followed by introduction to the relevant machineshop and manufacturing tools and engineering terminologies, blue print interpretation, introduction of various tools for measurement of inner dimensions, depth, height, angular and coordinate measuring systems, surface finish and thread measurements. The aforementioned topics cover about 50% of the course. The remaining 50% is spent on teaching the students basic principles of welding, brazing, milling, turning, and precision machining, including the use of CNC programming and CNC lathe machine operations. The principles will be augmented with workpiece practices the students will be assigned to complete using the machinery in a state-of-the-art machine shop facility.

The students are also introduced to micro-electro-mechanical systems (MEMS) and the various commonly used micro fabrication technologies. Approximately 15% of the course is currently devoted to this topic and is expected to grow in the future. Finally, this laboratory requires student report preparation and presentation of select projects. Although students have had prior training in report preparation and realizing that this is their first laboratory course, early on in they are reminded of the basic rules of laboratory report preparation and presentation of the results. Each of the first three laboratories is 2 credits, encompassing one hour lecture and three hours of lab per week. The lecture material and laboratory experiments are closely integrated based on the experience suggested by previous work in this field. [4-5].

Instead of requiring each student to submit an individual report, students will be split into small groups (no more than 3) and each group will be required to submit one laboratory report. This approach will encourage teamwork. Various software such as Microsoft PowerPoint, Microsoft Word, and Microsoft Excel will be used to prepare the laboratory report and presentations. Students are required to specify their specific share of contribution in conducting the experiment and preparation of the report.

Lab I was initially scheduled to be offered for the first time in the fall of 2004, however due to the late delivery of a number of equipment, it was offered until the spring of 2005 with a total of 8 students.

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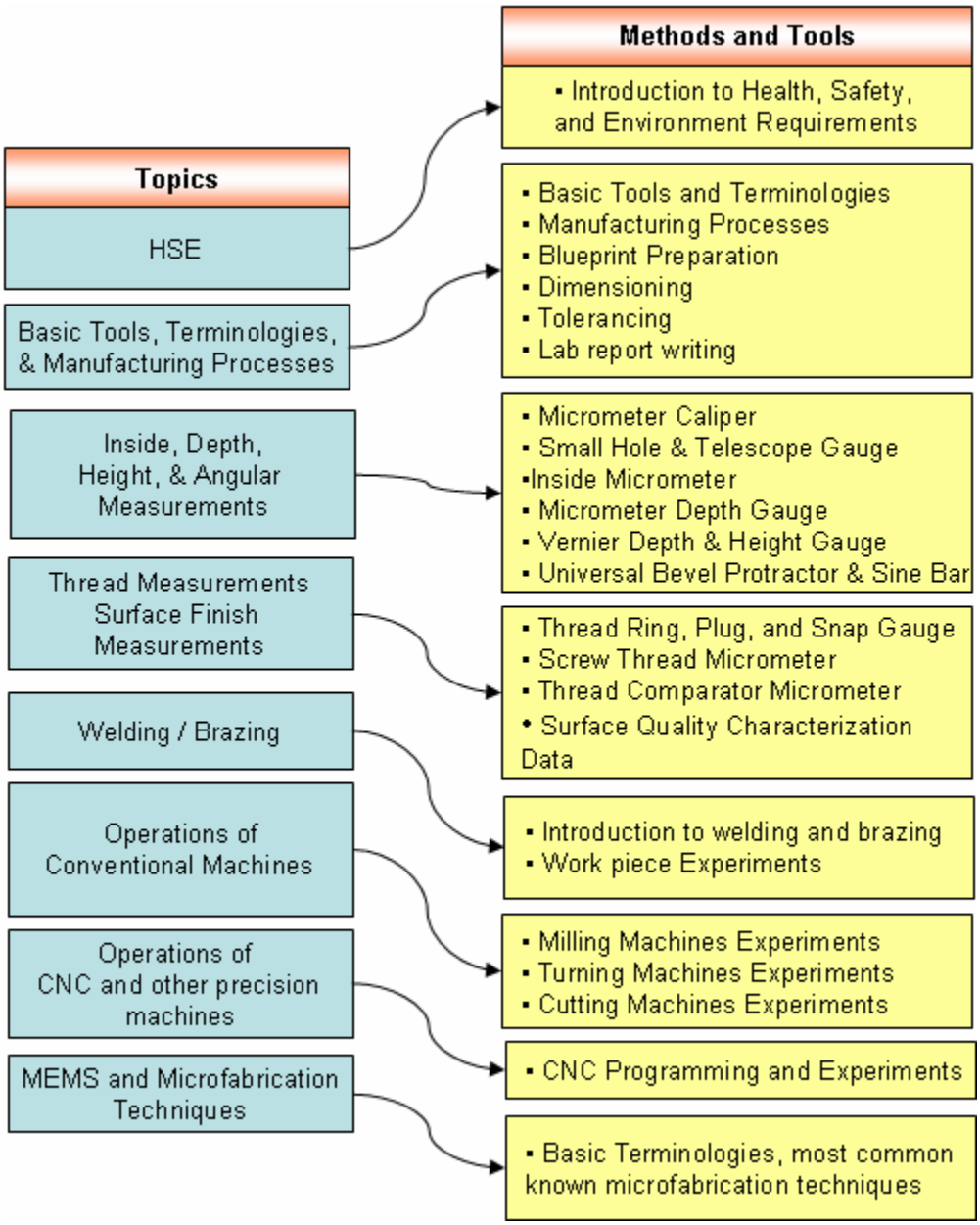

Figure 2. Topics, methods and tools used in Machine Shop and Manufacturing Lab

Lab II – Basic Measurements Laboratory

The second laboratory, which is offered in the spring semester of the sophomore year, is the Basic Measurement and Instrumentation Laboratory (Lab II). This lab covers measurement, instrumentation, and calibration techniques for measurement of basic parameters such as length, volume, density, temperature, pressure, force, strain and stress, velocity, and volumetric flow rate. The students will also learn principles of computer-controlled data acquisition and analysis techniques. Another important component of this lab is error and data uncertainty analysis techniques. Early on in the semester students will do experiments that will require such calculations and will prepare them for performing such analysis as needed in the remainder of

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the semester. At this stage the students are also introduced to the concept of instrument calibration and reliability analysis. The specific experimental subjects are shown in Figure 3.

The lab will provide an ideal forum to hone students' ability to express their results in written and oral forms. Similar to Lab I, students are split into small groups (no more than 3) and each group is required to submit one laboratory report. This approach will encourage teamwork. Software such as Microsoft PowerPoint, Microsoft Word, and Microsoft Excel will be used to prepare the laboratory report and presentation. Students must specify in their report their specific fair share of contribution to conducting of the experiment and preparation of the report.

The students are given a laboratory manual that provides them basic information about the various experiments, including background information and lecture materials on each experiment. Students will use their laboratory manuals to lead them through their experiments, and each group will be required to keep a data sheet [6] in which the experimental results are documented. Using the laboratory manual and the data sheet, a laboratory report will summarize the experiment performed. Each group's data sheet and final report will be submitted for grading.

Similar to Lab I, Lab II is a two-credit course with four contact hours per week (one hour of lecture and three hours of laboratory). In this laboratory Junior students are directed to study the theory behind and to conduct experiments with various measurement and calibration techniques for basic parameters such as pressure, temperature, mass and volumetric flow rate. The relationship between the parameter measured and the experiment conducted can be found in Figure 3. This program of ME laboratories was executed for the first time in the fall semester of 2004 and it is still in the process of expansion and enhancement.

Lab III – Core Subject Measurements Laboratory

The Core Measurement Laboratory, which is offered in the spring semester of the junior year, focuses on the core subjects of mechanical engineering such as fluid mechanics, heat transfer, thermodynamics and combustion, mechanics and material fracture analysis, automation and control. The prerequisite for Lab III is the basic measurements lab (Lab II). Lab III is being offered for the first time this spring with a total of 16 students who all successfully passed Lab II. Similar to Lab I and II, Lab III is a two–credit course and has similar contact hours per week. Students can expect to do 10 experiments per semester, 2 to 3 experiments in each of the four speciality areas of fluid mechanics, heat transfer, mechanics, and automation/control. The specific experimental topics are listed in Figure 3. Moreover, each semester on average two experiments are done as demonstrations only by the instructor, for which the student are required to prepare a report based on their observation of the experiment and the data collected by the instructor or lab demonstrator at the site. Report preparation and presentation skill requirements are similar to those of Labs I and II. Approximately one hour per week is devoted to lectures and three hours for conducting laboratory experiments. Students are provided with a laboratory manual that provides basic information about the experiments and the relevant theory involved.

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Lab IV – Advanced Measurements Laboratory

The objective of the Advanced Measurement Laboratory, an elective laboratory course offered in the senior year and open to both senior and graduate students, is to introduce the students to advanced measurement techniques and more complex engineering systems, laboratory data regression analysis, report writing and presentation of the results. This lab is scheduled to be offered in the fall of 2005. The prerequisite for this lab is lab III or graduate student good standing status.

Unlike the other three laboratory courses that are 2 credits each, Lab IV is a three-credit course with two hours of lecture per week and three hours of laboratory. The sample subjects to be covered in this laboratory are depicted in Figure 3. As seen there, the topics include

- Machinery diagnosis, balancing, and vibration testing
- Pipe surge and water hammer tests
- Cavitations tests
- Air conditioning and refrigeration system tests
- Condensation and boiling heat transfer analysis
- Multiple component flow separation processes
- Multi-phase flow mapping and regime prediction
- Open and close-loops for motion control
- Laser velocimetry analysis
- Particle image velocimetry (PIV)
- Microfluidics and micro energy systems

In all of the four laboratories in addition to the professor in charge, a technician and a laboratory engineer support the lab by maintaining the experiments and the equipment involved, upgrading of the apparatus and the instruments, and introducing new experiments.

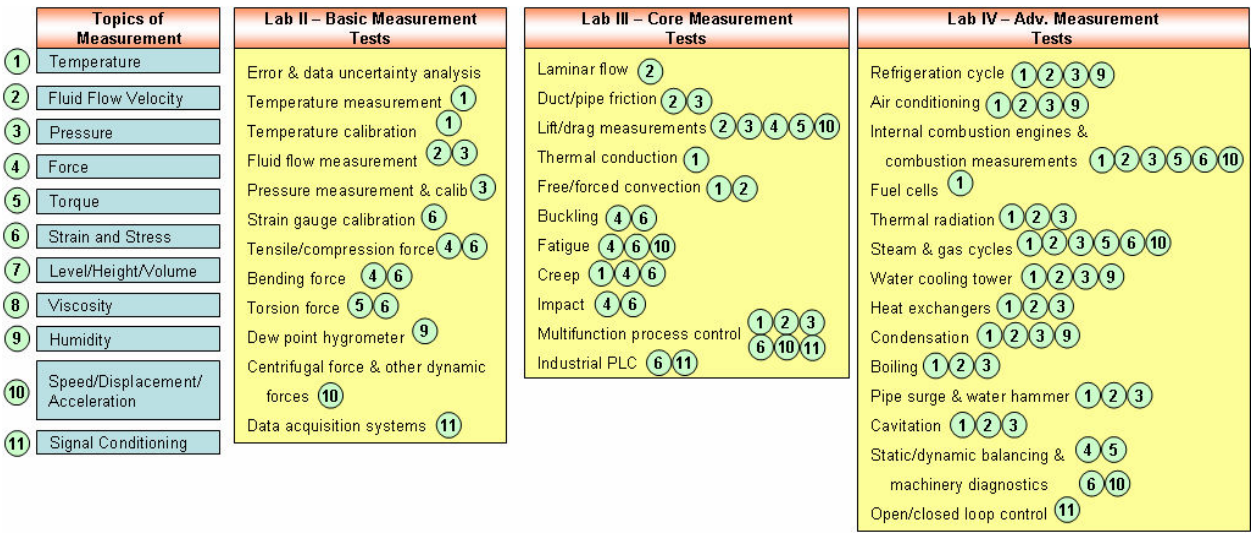

Figure 3. Topics and related experiments covered in ME Lab II, III, and IV

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Summary and Conclusions

Details of a series of four mechanical engineering undergraduate laboratories designed to address the needs of a modern mechanical engineering program were covered in this paper. Lab I includes introduction to basic tools and manufacturing techniques, including various machining terminologies, operational principles of the tools involved, and student experiments with work piece fabrication using the various machinery in the laboratory. The student will also learn basic related drawing skills and blue print interpretation. Lab II offers lectures and corresponding experiments on basic measurement and instrumentation techniques. Lab III deals with core subject measurements in mechanical engineering and offers experiments in the major specialty areas of thermo-fluids, mechanics, materials science, automation, and control. Lab IV is offered as a technical elective course in the senior year, covering advanced measurement techniques and is open to both senior and graduate students. The proposed model, while decouples the labs from various courses taught, offers a sequence that accommodates parallel offering of the laboratories with corresponding courses. Decoupling of the labs from the courses makes it possible to better maintain the labs by assigning a full time technician and lab engineer to the four labs to support the professor in charge of the labs, thus eliminating the uncertainty associated with various professors teaching the courses involved and the degree they may consider the lab integration in their courses important to better learning of the subject matter by the student in a typical mechanical engineering curriculum. We believe the information provided in this paper can serve useful for academic institutions who are considering revising their laboratories and/or plan to introduce new labs in their mechanical engineering program.

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Biography

MICHAEL OHADI, Ph.D., is a professor of mechanical engineering and the program director for mechanical engineering at the petroleum Institute. An internationally recognized authority in enhanced heat and mass transfer, has published over 140 refereed technical papers, is a fellow member of both ASME and ASHRAE, and has won numerous awards from both societies.

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