AC 2010-1048: INTRODUCTION TO MECHANICAL ENGINEERING - A HANDS-ON APPROACH

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Introduction to Mechanical Engineering - A Hands-On Approach

Abstract

In this paper, the development and evolution of a sophomore-level introduction to Mechanical Engineering (ME) class – ME2505 Mechanical Engineering Analysis and Design – is presented. The primary course objectives are to introduce students to the technical aspects of ME and to help students develop general skills needed to be successful ME students and engineer. These objectives are achieved through a hands-on, project-based laboratory coupled with complementary theory-based lectures. This class differs from typical introduction to engineering courses because it is offered to sophomores, which enables higher-level engineering content to be covered. The topics addressed in this paper are the initial development of the course, the evolution of the course over the past eight years, the current state of the course, student assessment of the course, and plans for future development.

1. Introduction

In this paper, the development and evolution of the sophomore-level introduction to Mechanical Engineering (ME) class at Villanova University (VU) – ME2505 Mechanical Engineering Analysis and Design (MEA&D) – is presented. This course focuses on introducing ME through a hands-on, project-based laboratory coupled with complementary theory-based lectures. First introduced eight years ago, this course has gradually evolved based on student, instructor, and faculty feedback. For example, the effectiveness of different laboratory activities has been evaluated using student surveys, the results of which have been used to direct modifications, and in some case replacement/redesign, of laboratory activities. Most recently, a greater focus has been placed on updating the lecture component of the course, with a specific emphasis on team-based active-learning. Future efforts in the course include the integration of content from state-of-the-art topics, such as mechatronics and nanotechnology, into both the laboratory and lecture. The topics addressed in this paper are the initial development of the course, the evolution of the course over the past eight years, the current state of the course, student assessment of the course, and plans for future development.

This MEA&D class differs from typical introduction to engineering classes[1-14] in two main areas: 1) the class is offered to sophomore students and 2) the inclusion of higher-level engineering content. First, this class is offered to sophomore students, while typical introductory engineering courses are offered to freshmen[1-12]. The Villanova University College of Engineering features a common freshman year and thus, students do not join their major department until their sophomore year, when this course is offered. It should be noted that some other universities do offer Sophomore level introduction to engineering courses[13,14], but they often tend to focus heavily on the design process, which is covered, but is not only focus area of the class. This enables the MEA&D instructors to offer the students more challenging hands-on projects, homework assignments, exams, and design projects, which leads to the second difference. Because this class is offered to sophomore students, the scope and difficulty of the engineering content included in the class is quite broad – covering all main aspects of mechanical engineering as well as general engineering content. Please note that there are introductory engineering classes that cover advanced content[1,2], but their scopes are more focused.

Before the development of MEA&D, the Department of Mechanical Engineering required a typical lecture-based introduction to ME design course for incoming sophomores. The primary motivation for the development of MEA&D was to give students hands-one experience in engineering, thus better preparing them to succeed in the ME curriculum. Based on this, the course objectives are 1) to introduce students to the technical aspects of ME, 2) to help students develop general skills needed to be successful ME students, 3) to introduce students to design, 4) to emphasize the role that engineering plays in contemporary society, 5) to impart a sense of the creativity and innovation inherent in ME, and 6) to improve professional skills necessary for successful engineering careers. A secondary objective is to excite students about the ME profession, and motivate them to continue with the arduous degree process. These objectives are achieved through a hands-on (in some cases open-ended) project-based laboratory, which emphasizes the engineering design process, coupled with complementary lectures that provide *just-in-time* information required for the laboratory.

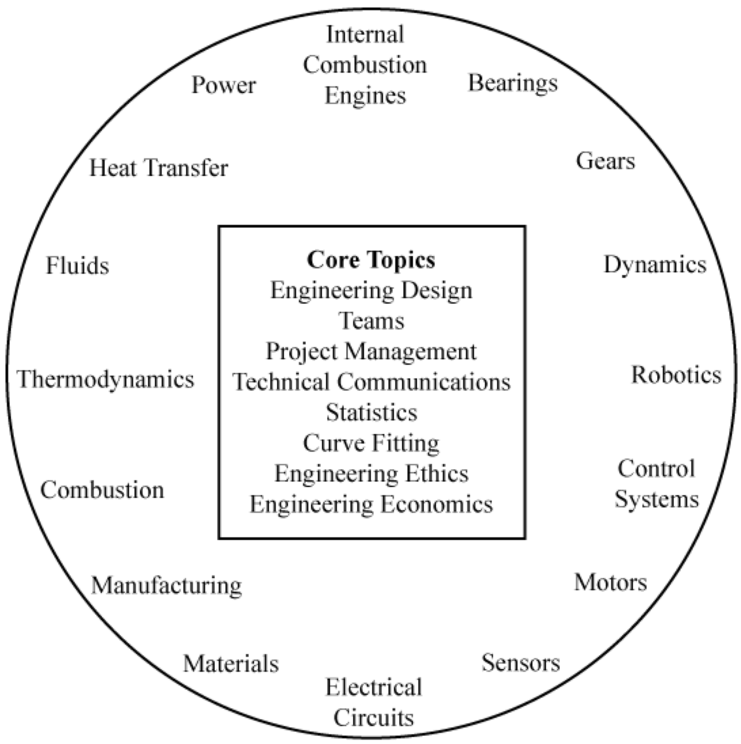

Figure 1: Chart showing the topics covered in MEA&D. These consist of general engineering design and analysis topics (shown inside the central rectangular box) as well as ME sub-area-specific topics taken from Thermal/Fluid Systems, Dynamic Systems, Solid Mechanics, and other engineering subjects.

The course consists of 3 lectures (50 minutes each) and one laboratory (150 minutes) per week. The topics covered can be broken into two categories, as seen in Figure 1: *Core ME Topics* (located inside the square) and *Technical ME Topics*. Each of these areas is elaborated in the following.

Core ME Skills: The core ME skills covered in this class focus on preparing students for success in the ME curriculum. They primarily come from the areas of design, engineering professional skills (for example teams, ethics, and economics), and technical content used throughout the ME profession (for example statistics and curve fitting).

Technical ME Topics: The technical topics covered are relatively broad, touching on content from thermal fluid systems, dynamic systems, solid mechanics, as well as some other typically non-ME areas. There is some flexibility in these topics, allowing the lecturer to draw upon his/her own area of expertise.

Student reaction to this course has been overwhelmingly positive, as seen from end-of-course surveys. These surveys place the laboratory section of this course in the top quartile of all courses taught in the College of Engineering in areas concerning intellectual stimulation, amount learned, and overall value. For a more detailed discussion of student survey results see section 5.

The remainder of this paper is organized as follows. In section 2, the initial development of the class is discussed, followed by the evolution of the class in section 3. Then, in section 4 the current status of the class is discussed, followed by student reaction in section 5. In section 6, the future direction for the class is presented. Finally in section 7 conclusions are presented.

2. Initial Course Development

This course was initially developed in the Fall of 2000, starting from an existing lecture course in introductory design. The instructors responsible for this design course had anecdotal evidence that a decreasing number of students were coming into mechanical engineering with hands-on experience – for example, taking things apart to see how they work. This was bolstered by informal class surveys, which revealed that less than 5% of students had ever taken an engine apart. The instructors were concerned that this lack of hands-on experience could negatively affect student learning. For example, it might be difficult for students to theoretically understand gear design if they had never held a gear in their own hands. Thus, the course topics were reviewed and revised to introduce design with a hands-on component that allowed the students to work directly with real parts, rather than just working conceptually with drawings and ideas.

Several basic topics were carried over from the initial design course, including the design process, units and unit conversions, simple statistics and project management while a new emphasis on an introduction to the basic mechanical engineering disciplines through hands-on activities was added. New topics were taken from ME areas including solid mechanics, thermal-fluids, materials/manufacturing and dynamics/controls.

Each discipline was then examined to determine how best to present these topics in an interactive method. The instructors decided to use two hands-on activities in which the students would reverse engineering existing designs to analyze the choices that were made, and one design competition in which the students would build their own design and evaluate it against other designs.

Solid Mechanics and Materials/Manufacturing: The topics of solid mechanics and materials and manufacturing were introduced through the reverse engineering of a hand drill. During lecture, students were taught basic gear and bearing design concepts including background theory, available components, and standard applications. They also learned basic material properties and manufacturing methods. In the laboratory, groups of students were given a standard hand drill to reverse engineer. During the deconstruction they examined parts of the drill and answered design questions. These questions included identifying the type of bearings and gears and why they were chosen, identifying the motor and drawing a wiring diagram, and indentifying the materials and manufacturing methods and why they were used. Finally students needed to reassemble the drill, and have it working properly by the end of the class period.

Thermal-fluids: The thermal-fluids discipline was introduced through the reverse engineering of a four-stroke internal combustion engine. In lecture students were taught the Otto and Diesel cycles and how these were realized using the internal combustion engine. In laboratory, groups of students were given a lawnmower engine to reverse engineer – they examined the parts, answered questions about the design choices and then had to reassemble the engine, and have it working properly by the end of the class period.

Dynamics and Controls: Dynamics and controls was introduced though a robotics design competition. Students used Lego Mindstorms kits to build and program a vehicle to accomplish a series of tasks. The vehicle design included aspects of the previous projects including proper gearing design and motor control. Student groups them competed against each other for speed and accuracy of task completion.

3. Course Evolution

Over the past eight years since the course was first conceived, there has been a significant amount of course evolution. This evolution is discussed for each component of the class (Lecture and Laboratory) in the following.

3.1 Lecture Evolution

The content of the lecture section of the course changed in reaction to the following influences: 1) The content of the freshman engineering program, 2) The need for additional curriculum content in professional engineering skills, and 3) The expertise of the instructor. Each of these influences is discussed below.

Freshman Engineering Content: The freshman engineering course changed from a design, graphics and programming course to one that surveyed the various fields of engineering. This put a greater demand on the Design & Analysis class to teach the concepts of the design process, design for manufacture and cost estimation.

Professional Skills: Course material was added to the lecture part of the course to include all varieties of engineering presentations, teamwork skills, leadership skills, conflict resolution, project management and the importance of continuing professional development. Students were introduced to the licensing procedures for becoming a professional engineer in the United States.

Instructor Expertise: A very positive aspect of the lecture part of the course was the ability of the instructor to introduce material in their particular fields of study and research. A professor with background in CAD and computer graphics could introduce the use of graphics in engineering analysis and design. A professor with background in thermo-fluid design could discuss topics of current interest in engineering. A professor with background in Mechatronics could show how electrical engineering concepts were relevant to mechanical engineers.

3.2 Laboratory Evolution

It is noted that the initial version of the course (as described in section 2) met on a standard class schedule (MWF 50 minutes per class meeting). This made it very difficult to accomplish the drill and engine deconstruction projects because they were spread over several weeks. This lead to both logistical and pedagogical issues. Thus, after three years of the initial version, a course revision was undertaken, in which a dedicated laboratory section was added. This lab allowed the hands-on activities to be more easily completed. With a weekly lab section, additional hands-on activities were added. As the years have progressed the content of the laboratory section has also evolved. Using student, instructor, and faculty input, labs have been modified and replaced to better serve the students.

4. Current Status of the Course

As it stands now, the course is extremely hands-on and focused on active-learning (both laboratory and lecture). As a guide to the current status of this course, the schedule from Fall 2009 is shown in Figure 2. As can be seen from the schedule, the material covered in the lectures and labs are closely coordinated in order to reinforce each other – this is highlighted with arrows. Examples of this coordination are highlighted below.

Introduction to the design process: In week 1, the engineering design process is presented in lecture, followed by the first laboratory assignment, which is to use the design process to design, build, test, and revise a device to launch a ball at a target. This device must be built with very limited pre-specified materials.

Machine Components: In weeks 1 to 4 students are learn about gears, bearings, and motors in the lecture. In week 4 in the laboratory, they dissect things such as drills, saber saws, grinding machines, and air compressors and answer questions about the parts and designs of these tools.

Internal Combustion Engines: Lectures about internal combustion engines in week 6 and 8 is coupled with the laboratory project in weeks 8 and 9, which is to reverse engineering a lawn mower engine – dissecting it and putting it back together, taking measurements and answering questions about things like compression ratios, magnetos, valve timing, cooling, venturis in carburetors, and flywheels.

Measurements: Lectures from weeks 8-9 discuss electrical circuits and the construction of an amplification circuit. In weeks 10 and 11 the content from lecture is reinforced in the laboratory. They use the amplification circuit in lab to amplify the voltage from a thermocouple. They then calibrate thermocouples and thermistors and then use them to measure temperatures of cell phones and laptop computers.

LECTURE INFORMATION		LABORATORY INFORMATION
Date	**Topic**	**Oral presentations will be given daily**
Week 1	Mechanical Engineering Design Gears and Gear Trains	Project: Ball Launcher Topics: Hands-On, Testing & Revising, Design
Week 2	Gears and Bearings Engineering Teams	Project: Compressed Air Vehicles Topics: Hands-On, Testing & Revising, Design
Week 3	DC Motors Problem Formulation/Solving	
Week 4	DC Motors AC Motors Concept Generation	Project: Hand Drill Dissection Topics: Bearings, Gears, Motors
Week 5	Accuracy, Precision, Error, Sig Figures Systems of Units and Unit Conversions Project Planning	Project: LEGO NXT Cranes Topics: Gears, Motors, Torque, Power, Matlab, Control systems
Week 6	Sensors Thermofluid Engineering Technical Comm – Presentations	
Week 7	Combustion IC Engines	Project: Introduction to BeetleBots Topics: Robotics
Week 8	IC Engines Circuit Analysis Project Management	Project: Engine Dissection Topics: Combustion, Measurement, IC Engines
Week 9	Operational Amplifiers Statistics Probability in Design	
Week 10	Statistics Decision Making	Topic: Labview - Introduction
Week 11	Curve Fitting Engineering Ethics	Project: Op-amps, Electrical and Thermal Measurements Topics: Sensors, Heat Transfer, Thermo
Week 12	Curve Fitting Mechanisms Codes and Standards	Project: Design and Perform an Experiment Topics: Statistics, Curve Fitting
Week 13	Dynamics Technical Comm – Report Writing	
Week 14	Control Systems	Project: BeetleBot Competition Topics: All Topics

Figure 3: MEA&D schedule for Fall 2009. The relation between the topics in the lecture and laboratory are shown with arrows.

Bringing the class together: In the final laboratory assignment (weeks 12 and 13) the students may use any or all of the information that they learned in the lectures to design and run their own experiment to determine information asked of them about something of which they may not be familiar such as Shape Memory Alloys or Wind Turbines. All project results are communicated through written and oral reports, emphasizing the fact that communication skills are extremely important for practicing engineers.

In addition to the weekly in class laboratories, students also have a team-based semester design project. Design teams are formed early in the semester when the students are learning about engineering design. The students work with these teams throughout the semester on smaller projects, labs, homework, and the semester design project. The project in 2009 was the design and construction of a "Beetlebot" which is a robot which weighs less than three pounds and fights against other "Beetlebots" in an enclosed eight foot by eight foot arena. This competition is held on a weekend at the end of the semester and is attended by students, faculty, friends, family, alumni, and visitors. Students have been known to attend this competition with the name and color of the robot they are supporting painted on their faces and bodies.

It is also important to point out that the lecture section of the course has become more hands-on and student centered in order to mimic the laboratory section. For example, when discussing DC motors, small DC motors and dissected and all the theoretical components are identified. This is followed by an open-ended DC motor sizing exercise. The design teams alluded to in the previous paragraph also play an important role in class, serving as a discussion group.

5. Student Reaction to the Course

The results from end-of-course surveys from multiple years are presented. Both components of the course (lecture and laboratory) are rated separately and, thus, are discussed separately below. The results are drawn from three data sets:

D1) Survey results for the lecture portion of the course are taken from end-of-semester surveys from 2006-2008. This group consisted of 185 students ('06 – 58, 07' – 75, '08 – 52).

D2) Survey results for the overall student perception of the laboratory section are taken from end-of-semester surveys from 2006-2008. This group consisted of 215 students ('06 – 73, '07 – 69, '08 – 73).

D3) Survey results for specific student perception of the laboratory exercises are taken from end-of semester surveys from 2003-2007 – total number of students was 407 ('03 – 102, '04 – 85, '05 – 81, '06 – 73, '07 – 66).

5.1 Lecture Evaluation

The student response to the lecture section is somewhat variable. Anecdotally, the students seem to enjoy the more engaging lectures (motors, internal combustion engines), while not enjoying the lectures regarding more common topics (unit conversion, significant digits). Thus, the results from data set D1, discussed above, are somewhat lower than would be desired. Student responses to the following three statements:

S1) I found the course intellectually stimulating.
S2) I learned a great deal from the course.
S3) Rate the overall value of this course.

were 4.1, 4.2, and 4.2 respectively. This placed the rating of the lecture potion of this course in the top half of courses in the College of Engineering and the Mechanical Engineering Department.

5.2 Laboratory Evaluation

Student reaction to the laboratory section of this course has been overwhelmingly positive. Students are extremely motivated by the opportunity to perform hands-on experiments in an open-ended engineering context. From data set D2, when students were given the same three statements above (S1-S3) for the laboratory section, student responses were 4.5, 4.5, and 4.6 respectively. This placed the rating of the laboratory section of this course in the top quartile of courses in the College of Engineering and the Mechanical Engineering Department.

In data set D3, students were asked more direct questions regarding the laboratory. Some of the results are highlighted in Figure 3, which shows student responses from some of the statements in this survey.

A key component of the laboratory section is its hands-on nature. Figure 3(a) shows the responses to the statement:

S4) Hands-on type assignments are important to learning.

Students rated their agreement with this statement at 4.8/5. Thus, the laboratory instilled an understanding of the importance of hands-on learning in the students.

In Figure 3(b) student assessment of the effectiveness of laboratory exercises in achieving their academic goals is shown. This data is a composite response from a number of statements including:

S5) The Rocket lab increased my belief that testing and revision are important.
S6) The statistics lab increased my understanding of statistics.
S7) The circuit and temperature lab helped me better understand electrical circuit testing equipment.
S8) The Drill/Tool Dissection lab increased my understanding of the relationship between assembly and design.
S9) The Racecars lab increased my understanding of gears.

The total response 4.0/5 is quite positive, showing the broad effectiveness of the laboratory.

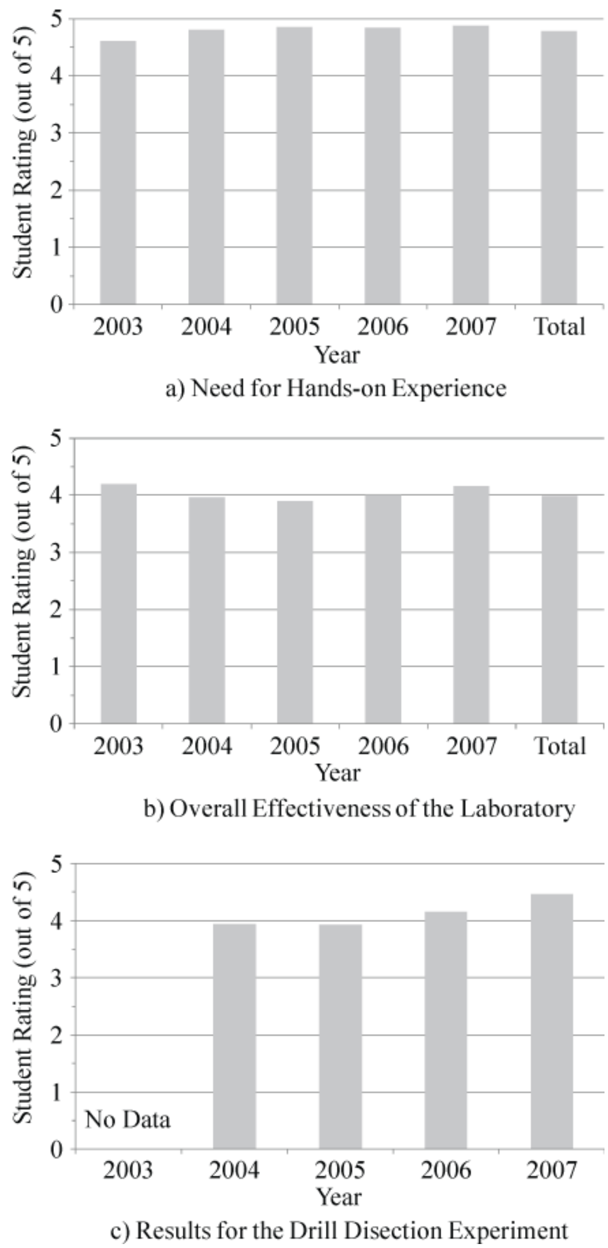

Figure 3 – Bar graphs showing student responses to survey questions regarding a) the students' perceived need for hands-on experiences to improve learning, b) the students' perception of the effectiveness of the hands-on experiments performed in the ME2505 laboratory, and c) the students' perceived effectiveness of an example experiment (power tool dissection). Note that c) shows increased experiment effectiveness over time. Results are from data set D3.

It should be noted that some labs are better received than others. This information has been used to improve or in some cases justify the removal of laboratory exercises. An example of the constant increase in laboratory effectiveness is shown in Figure 3(c), which shows student response to statement S8 from the list above. A constant increase in the effectiveness of the laboratory is seen throughout the years, which was in response to student surveys.\

6. Future Directions

As the course continues to evolve in the future, the focus is being put primarily on the lecture portion of the class. As shown in the student surveys, the lecture portion is not as intellectually challenging as the laboratory section. To address this issue there is a planned shift in the lecture section to team-based open-ended problem solving – this will allow the difficulty and scope of the problems solved for the lecture section to be increased without putting increased strain on the students. In addition, there is an increasing emphasis being put on active learning to better engage and challenge the students.

In addition to the planned pedagogical changes being incorporated into the lecture section, there is also a planned increase in cutting edge topics such as nanotechnology and mechatronics. For example, smart material actuators (piezoelectric, shape memory alloy, etc.) will be discussed in terms of material properties, application, and design issues. Other content changes being considered is a shift to more difficult design topics such as optimization and advanced decision making techniques.

In the laboratory section, planned changes are not as significant due to its success. Plans are to continue to develop the existing laboratories based on student feedback. New laboratories will be designed when needed to complement the planned changes to the lecture section.

7. Conclusions

In this paper, the development and evolution of the sophomore-level introduction to ME class at Villanova University – ME2505 Mechanical Engineering Analysis and Design – was presented. This course focuses on introducing ME through a hands-on, project-based laboratory coupled with complementary theory-based lectures. Thus, the course objectives are 1) to introduce students to the technical aspects of ME, 2) to help students develop general skills needed to be successful ME students, 3) to introduce students to design, 4) to emphasize the role that engineering plays in contemporary society, 5) to impart a sense of the creativity and innovation inherent in ME, and 6) to improve professional skills necessary for successful engineering careers. Student reaction to this course has been overwhelmingly positive, as seen from end-of-course surveys. These surveys place the laboratory section of this course in the top quartile of all courses taught in the College of Engineering in areas concerning intellectual stimulation, amount learned, and overall value. The topics addressed in this paper were the initial development of the course, the evolution of the course over the past eight years, the current state of the course, student assessment of the course, and plans for future development.

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