Development and Implementation of a Common Investigative Methods Course for Undergraduate Engineering Students

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Introduction

A common concern among engineering faculty is that our students, while competent with engineering design concepts and processes, are increasingly incompetent in pragmatic application of those concepts. Historically students with an interest in engineering "tinkered" with things, had experience building and testing ideas, and generally knew their way around a toolbox. That understanding can no longer be assumed, as technological processes increasingly are treated as black boxes.[1] In response to this concern we developed and have taught a course designed to introduce sophomore students in engineering to field and laboratory techniques used in biological systems, agricultural, and environmental engineering. Our experience has been that students are generally very resistant to discovery-based laboratories since by definition this approach lacks explicit step-by-step guidance.

The primary objective of the course is to provide students with physical applications of theoretical concepts. This course is a common requirement across the undergraduate curricula for Biological Systems Engineering and Agricultural Engineering at Texas A&M University, linking freshman and sophomore engineering science courses to junior and senior-level courses through common design concepts and projects. Students work in small groups to design and conduct experiments over the course of the semester. Students are introduced to these techniques through hands-on investigation of engineering concepts, involving processes as simple as wiring of motors, assembling and testing pumping arrays, and measuring potentiometric gradients, to processes as complex as designing and programming analog and digital systems. Students communicate the results of their work in weekly laboratory reports. A faculty member with expertise in that specific topic area teaches the lecture component of each section. The pedagogic strategy is to provide students with experience that supports the theory they are learning in foundation engineering courses and to link the concepts of conservation of mass and energy across disciplinary focus areas (biosystems, mechanical, food, environmental). The course is structured as one hour of lecture followed by two laboratory sessions of three hours each, for three semester credit hours. Students work in teams of three, with an enrollment of 36 for the first year. We developed the course with five sections: 1) Investigative Methods, 2) Mechatronics, 3) Environmental Processes, 4) Energy Systems, and 5) Geo-Metrics.

Section 1: Investigative Methods
The objective of the first section of the course is to introduce students to tools and approaches used in the engineering profession. This introduction is designed to prepare the students for discovery-based laboratory experiences.[2] The first section of this course was developed to give students the confidence to approach open-ended problems by providing frameworks for investigation that are commonly used in the engineering profession. This section is composed of three lecture/lab sets covering the fundamental skills needed by engineers: Engineering Design Methods, Scientific Methods, and Project Management Methods. Each course topic is structured with a lecture describing fundamental processes or tools followed by laboratories utilizing one of the three investigative methods.

A common activity is used throughout each section to provide continuity of experience in applying each method. The first section activity includes design, construction, and analysis of a trebuchet.[3] The design component utilizes a mathematically rigorous description of trebuchet kinetics.[4] Students validate a design model and use that model to design a trebuchet meeting specific design constraints.[5] The students apply project management skills to construction and calibration of the physical model of the trebuchet. Many engineers spend much of their careers implementing the design of others, making project management a critical skill. Finally, the students will analyze the performance of their trebuchets by altering a suite of variables and empirically testing hypotheses. This lecture and lab set will provide students with explicit guidance for investigating problems using the scientific method.

Section 2: Mechatronics
The second section (fourth lecture and lab set) will provide students with experience with electronics integrated into mechanical systems. The laboratories will use structured-language programming, logic processes, and electronic control systems as requisite tasks. The objective is to link problem-solving skills developed in Lectures 1 through 3 with explicit tools, and to further introduce students to discovery-based learning. The students will construct and calibrate a small robot system using a micro-controller (the Board of Education robot, BOE-Bot).[6] Students learn linear programming using P-basic to control the microprocessor. In the second lab/lecture series of this section they control the robot using linear programming with electronic sensors (infrared emitters/detectors, light sensors, and contact sensors) to solve a set of complex logic problems. Finally, they apply these skills in a competition to lay siege to a castle by attaching small trebuchets to the tops of the BOE-Bots during the third lecture/lab series.

Section 3: Environmental Processes
The objective of this section is to introduce students to sampling and analysis of environmental systems. This section is composed of two lecture/lab sets. The first addresses water quality. Students are provided information on water quality parameters of concern for wastewater treatment plant (WWTP) discharge. The students develop testable hypotheses for upstream-downstream water quality at a WWTP outfall. Students tour the activated-sludge WWTP in the process of collecting samples. Students design and implement a sampling plan, including 48-hour continuous monitoring of DO, pH, conductivity, temperature, and depth using YSI Datasondes.[7] Students bring water samples to the Texas A&M University Water Quality Research Laboratory where they analyze the water for solids, biochemical oxygen demand,

chemical oxygen demand, and nutrients. The second week they review the data from the WWTP and test the effects of altering C:N:P ratios using bench-scale activated sludge systems.[8]

Section 4: Energy Systems
The objective of this section is to introduce students to energy systems through application and experience. The first of the three-lecture/lab series describes the thermodynamics of internal combustion energy systems. The students will have had a thermodynamics course, so the lecture will review critical principles. The laboratory includes measuring energy in various products using a bomb calorimeter and disassembling an internal combustion engine. The second lecture/laboratory series covers electrical energy systems. The laboratory activities include measuring current and voltage draw in a variety of electric motors (DC, AC two- and three-phase). The third lecture/lab in this series addresses power transmission. Students develop Bernoulli's equation using principles of conservation of mass and energy. Students then develop pump power curves from several electric motors with centrifugal pumps attached using pressure gauges and buckets/stopwatches.

Section 5: Geo-Metrics
The final section of this course includes three lecture/lab series on measuring features on the surface of Earth. The first series in this section is plane surveying using a dumpy level and differential global positioning system. Students measure eight points on a six-hectare field using both measurement devices, and calculate accuracy and precision of each method. The second series teaches the students to measure topographic features using both technologies. Students link this activity to the previous section by measuring the potential energy of water flowing in a concrete-lined channel at quartile depths. They observe the effects of the release of this energy at a point where the lining stops, resulting in dramatic erosion. Finally, students are introduced to geographic information systems using GIS-Hydro.[9]

Conclusions
Discovery-based learning is difficult to achieve. We have developed this course to address the concerns expressed from a number of quarters that our students are weak in applying what they know to solve complex problems. The approach we have taken is intended to reinforce critical concepts while instilling a sense of excitement about the profession of engineering. It is our contention that professional rigor and innovation in engineering are not competing concepts. Both are the products of commitment and excitement about a profession resulting in discipline and innovation. As Dr. Joe Bordogna said of innovation[10]:

> In 1999 the Economist magazine did a study of innovation in industry. A sidebar to the text read, "Innovators break all the rules, trust them." In this sense, innovation is the task of breaking the economic rules and being rewarded, over and over again…The "rule-breaking" theory of economics was actually developed in 1942 by the Austrian economist Joseph Schumpter. He described the hallmark of technological innovation as "the perennial gale of creative destruction," or in today's holistic thinking, "the great lever of creative transformation."

We must teach our students the methods for "breaking the rules," i.e., the methods that will provide the most rigorous (defensible) path to innovation in their professional careers.

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