AC 2012-4858: A PROBLEM-SOLVING AND PROJECT-BASED INTRODUCTION TO ENGINEERING TECHNOLOGY COURSE

Dr. Biswajit Ray, Bloomsburg University of Pennsylvania

Biswajit Ray is a professor and Program Coordinator of the Electronics Engineering Technology program at Bloomsburg University of Pennsylvania. He is active in industrial consulting in the area of power electronics.

A Problem-Solving and Project Based Introduction to Engineering Technology Course

Abstract

The motivation and implementation of an *Introduction to Engineering Technology* course, offered to freshmen electronics engineering technology students, are presented. The primary objective of this course is to improve the quantitative and qualitative problem solving skill of freshmen students during their first semester of college experience. This in turn contributes to their preparedness for subsequent science, math, and engineering technology courses, positively impacting student retention rate. The course presented herein also includes a number of hands-on projects to introduce the concepts of engineering design, prototyping, and testing. Soft skills such as formal report writing and team work, and orientation to engineering profession and industry are also key components of this course. Course-embedded assessment data supporting the objectives and student outcomes are also presented. Assessment data clearly indicate that even though the students consider this introductory course to be demanding and challenging, they do benefit from its analytical rigor essential to performing well in subsequent math, science, and engineering technology courses.

Introduction

Based on student feedback over the past few years, and often contrary to common belief, it has been determined that at our university the best contribution an introductory engineering technology course can make to incoming freshmen majoring in electronics engineering technology (EET) is helping to improve their quantitative and problem solving skills, which often lack due to non-rigorous math and science courses taken in high school. This approach to an introduction to engineering technology course contributes to students' preparedness for subsequent science, math, and engineering technology courses. Several introductory courses reported in the literature[1-3] were taken into consideration while planning the content of the course presented herein. The issues of remedial math preparation[4] and its impact on engineering technology student retention[5] were considered as well. After a careful review of the need of our students and the review of relevant literature, it was decided to focus on engineering problem solving early in the course by integrating concepts of algebra, geometry, trigonometry, and vectors. Optimization of single-variable problems is then introduced without using calculus knowledge since most first-semester freshmen take pre-calculus as their first math course (concurrent with the introduction to engineering technology course). Students are encouraged to use commonly available computational tools such as a calculator or a spreadsheet application to optimize engineering-specific variables of interest. Once the essential mathematical skills are reviewed and developed, additional engineering topics are introduced with a focus on further strengthening students' problem solving skillset. This is accomplished through electrical circuit analysis, analysis and synthesis of one-dimensional and two-dimensional motion, and fundamentals of engineering mechanics (primarily statics, stress, and strain).

The hands-on aspect to engineering is a key part of this course as well. Working as a group of two, students complete four mini projects: 1) designing a tallest possible paper tower, 2) prototyping and testing a music-engine printed circuit board, 3) designing, prototyping and testing a wireless remote controller, and 4) designing, constructing, and testing a spaghetti bridge. Engineering creativity, problem solving, teamwork, and formal report writing are emphasized through these mini projects.

Orientation to academic and social life on campus and exposure to real-world engineering is the other major part of the course. Academic success strategies and available university resources are discussed. Students are familiarized with the specific requirements for the EET major and the available academic resources within the department. Exposure to real-world engineering is emphasized via invited presentations by engineers from area industries and a field trip to a modern electronics design and manufacturing facility.

The specific objectives and associated outcomes, including assessment instruments, for this course are presented next. This is followed by detailed course content and a brief discussion on textbook selection issue. Quantitative and qualitative outcome assessment results are presented and discussed as well. Assessment data over the past three years clearly indicate that the problem-solving and project based introduction to engineering technology course presented herein is preparing freshmen students to successfully pursue electronics engineering technology major by improving their quantitative problem solving skillset and exposing them early on to real-world engineering via hands-on projects, invited presentations, and an industry field trip.

Course Objectives, Outcomes, and Assessment

The three main objectives of this course are: developing mathematical and problem solving skills for engineering analysis, exposing students to real-world engineering, and constructing and testing of simple electrical circuits and mechanical structures. The mapping between these three course objectives and student outcomes as defined by the Criteron-3 of ABET-TAC[6] is shown in Table I. Definitions of specific ABET student outcomes applicable to this course are listed below for the sake of completeness.

- *Outcome a:* Ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities,
- *Outcome b:* Ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies,
- *Outcome e:* Ability to function effectively as a member or leader on a technical team,
- *Outcome f:* Ability to identify, analyze, and solve broadly-defined engineering technology problems,
- *Outcome h:* Understanding of the need for and an ability to engage in self-directed continuing professional development, and
- *Outcome k:* Commitment to quality, timeliness, and continuous improvement.

Students are assessed for course objectives and outcomes using various direct and indirect assessment tools. Appendix-A shows an end-of-semester questionnaire for indirect assessment of course objectives and outcomes by students and Appendix-B shows a rubric for direct assessment of student teamwork effort. Additionally, course-embedded direct assessment of objectives and university-level end-of-semester faculty and course indirect assessment provide valuable input to the overall course assessment and continuous improvement process. Results from various direct and indirect assessment instruments are archived and processed annually to generate action items used as input to the course's continuous improvement process.

Table I: Mapping of Course Objectives to Student Outcomes

Course Objectives	Supported Student Outcomes (per ABET-TAC Criterion-3)
Developing mathematical and problem solving skills for engineering analysis	a, b, f, h, k
Exposure to real-world engineering	a, h
Hands-on construction and testing of simple electrical circuits and mechanical structures	a, b, e, k

Course Content

The four major components of the course are presented next. Based on this content, finding a textbook from the marketplace has been a challenge. A number of available textbooks[7-12] for an introduction to engineering/engineering technology course was reviewed. While each book has its strength, some of the potential textbooks assumed a level of math preparation much higher than our average freshman possess while the others emphasized the engineering profession and practices much more than the problem solving aspects of engineering. Based on this scenario, a custom textbook[13] was designed covering the college academic and social life, engineering profession and curriculum, real-world engineering, and engineering problem solving. Hands-on design and development projects, however, were supported by in-house course material.

- Orientation to academic and social life in college
    - Freshman year in college: Academic and social life expectation and reality
    - Available university support for academic and social concerns
    - Engineering and engineering technology professions
    - Academic success strategies for studying engineering technology
    - Electronics engineering technology program requirements
    - Get introduced to departmental faculty, support personnel, and laboratories
- Exposure to real-world engineering
    - Industry co-op experience presentation by a junior-level student
    - Presentation by an EET alumni working in industry for more than five years
    - Field trip to a modern electronics design, manufacturing, and testing company
    - Industry co-op experience and in-house research opportunities
- Problem-solving skill development
    - Engineering problem solving using algebra, geometry, and trigonometry
    - Single-variable optimization problems without using calculus concepts
    - Electrical circuit analysis: series, parallel, and series-parallel circuits
    - Applying position, velocity, and acceleration concepts to solve one-dimensional and two-dimensional motion problems including the effect of gravitational acceleration/deceleration
    - Engineering statics: vectors, forces, free-body diagrams, static equilibrium, tensile and compressive forces, stress, strain, and modulus of elasticity

- Hands-on engineering design and development projects
  - Build the tallest possible tower with an 8.5”x11” paper and 20” of tape
  - Wireless remote controller prototyping and testing using infrared transmitter/receiver circuits
  - Prototyping and testing a music engine printed circuit board
  - Building a bridge made from spaghetti and glue/epoxy with the objective of maximizing the ratio of load capacity to mass of the bridge
  - Develop technical report writing and team work skills

Orientation to academic and social life in college

During the first week of fall semester, new freshmen are oriented to the university academic and social life in relation to their freedom, responsibilities, and expectations and reality. Commonly encountered academic and social issues are discussed in conjunction with the available university resources to resolve such issues. Students are introduced to the engineering and engineering technology profession in relation to creative and challenging work, excellent opportunities, and necessary academic preparation. Academic strategies needed to be successful in a college environment such as commitment, perseverance, associations, working with peers, and limited part-time employment are emphasized. Students are introduced to the specific program requirements for the Electronics Engineering Technology program in addition to the general education requirements at the university level. They are also made aware of paid industry co-op experience as well as in-house research opportunities. This segment of the course ends with a lunch meeting with all faculty and staff members of the department, followed by a tour of the departmental teaching and research laboratories.

Exposure to real-world engineering

In this segment of the course, students are exposed to real-world engineering via invited lectures and an industry field trip. Since one of the requirements of the EET program is to complete a six-month full-time paid co-op experience in industry during their junior year, a returning student presents his/her industrial experience to the freshman class. As part of this presentation, the invited student also discusses his/her overall experience in the program and at the university. This presentation is followed by a second invited speaker who is a graduate of the EET program with a minimum of five years of industry experience in the engineering field. The students are introduced to day-to-day life of an engineer/engineering technologist who went through a program they just stared with. They not only learn about technical aspects of the presenter’s job but also the need to develop a strong interest in life-long learning and teamwork. This segment of the course ends with a field trip to a modern electronics company specializing in value-added contract manufacturing supported by design and engineering services. Through this field trip, students get an opportunity to talk to on-site engineers and engineering technologists while getting familiar with the multidimensional aspect of engineering including design, manufacturing, troubleshooting and testing, quality standards, customer interface, documentation, teamwork, and the need to have an interest in learning about and implementing new technologies.

Problem-solving skill development

Most students entering the EET program lack problem solving skill requiring integration of knowledge gained in various high school mathematics courses (e.g., algebra, geometry, and trigonometry). And for many of them, lack of maturity in mathematics is the root cause of academic problems encountered in math, science, and engineering technology courses. In order to alleviate this weakness, students are introduced to engineering problem solving strategy early on in this course. A couple of classes are used to review the key concepts of algebra, geometry, and trigonometry. It is followed by engineering-oriented problem solving including optimization of single-variable design without using calculus concepts. An example single-variable design optimization problem[7], considered difficult by most students, is stated below. Engaging in these type of problems helps students develop analytical as well as computational (for this class, either *Microsoft Excel* spreadsheet or *TI-89* graphing calculator) problem solving skillset without requiring calculus knowledge. Optimization problems are initially considered hard by most students; however, with practice they feel comfortable solving constrained design problems.

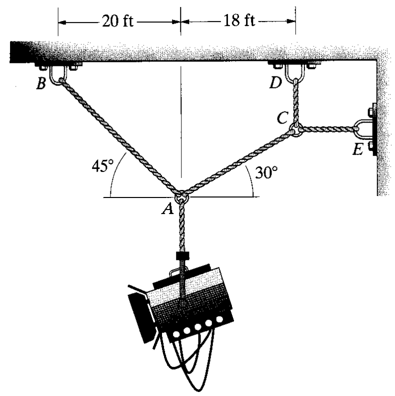
> *A tank is to be constructed that will hold 5×10^5 L when filled. The shape is to be cylindrical, with a hemispherical top. Costs to construct the cylindrical portion will be \$300/m^2, while costs for the hemispherical portion are slightly higher at \$400/m^2. Calculate the tank dimensions that will result in the lowest dollar cost. Neglect the cost of the base.*

Next, students are introduced to commonly-used electrical variables such as charge, current, voltage, power, and energy. This is followed by introduction of basic circuit laws such as Ohm's Law, Kirchhoff's Current Law, and Kirchhoff's Voltage Law. DC analysis of electrical circuits is undertaken next for series, parallel, and series-parallel circuits. Introduction of electrical circuit analysis not only motivates the EET students but also prepares them for a couple of circuit projects described in the next subsection. Problem solving skills are developed via analyzing various types of dc electrical circuits.

In order to prepare students for next semester's physics class while augmenting their problem solving skill, the concepts for position, velocity, and acceleration are introduced next. Basic motion equations are developed from the definition of key variables while avoiding the use of calculus knowledge. Problem solving in one-dimensional motion are introduced, first in horizontal direction and then in vertical direction including the effects of gravitational acceleration/deceleration. This is followed by the introduction of two-dimensional motion by treating projectile motion as two one-dimensional motions. Students gain a significant improvement in critical thinking and problem solving ability by engaging in motion related problems.

The final part of the problem solving segment focuses on vectors, various types of forces, free-body diagrams, static equilibrium of coplanar concurrent force systems, engineering statics under tensile and compressive forces, stress, strain, stress-strain relationship, Hooke's Law, and modulus of elasticity (Young's modulus). Solving statics problems is an excellent way to improve students' problem solving ability by integrating algebra, geometry, trigonometry, and force vectors. An example of such a problem[14] is shown next.

The system of cables suspends a 1000-lb bank of lights above a movie set. A technician changes the position of the bank of lights by removing the cable CE. What are the tensions in cables AB and ACD after the change?



<u>*Hands-on engineering design and development projects*</u>
Students are given the opportunity to design and test four hands-on projects as part of the course. This segment of the course is distributed throughout the semester, and is progressively more in-depth. Students work in groups of two students, and to encourage a strong teamwork culture the group members work together throughout the semester. Additionally, two written reports are required of students as part of this project segment.

Project #1
The goal is to build the tallest possible tower with an 8.5”x11” sheet of paper and 20” of tape. The base of the tower shall not be taped to the supporting surface, and the tower shall stand for at least 1 minute. Allotted time for this project is 45 minutes.

This project is carried out in class during the second week of semester in a friendly yet competitive environment. So far, the tallest tower built in class is 5′3″ high. Students seem to enjoy the experience while realizing the importance of thoughtful considerations and creative thinking even in a relatively simple design problem.

Figure 1: Pictorial view of the tallest paper tower designed and constructed in class.

Project #2
Students are given an opportunity to prototype and test a music-engine printed circuit board by soldering through-hole components. The prototyped music engine and the associated circuit schematic are shown in Figure 2. It is the electronic equivalent of a mechanical music box, and is activated by light falling on a photoresistor. The circuit includes a music generating integrated circuit (IC) preprogrammed with Christmas songs and five additional popular tunes. Students are able to experiment with the musical pitch by varying resistor R1 and the shape of the generated sound by changing the R-C network at pin-7 of the IC. The speaker is driven by a complementary pair of transistors, and negative feedback is provided by R3 to stabilize the dc voltage at the emitters of Q1 and Q2. This project introduces students to printed circuit board technology, hand soldering of electronic components, and a general understanding of audio electronics.

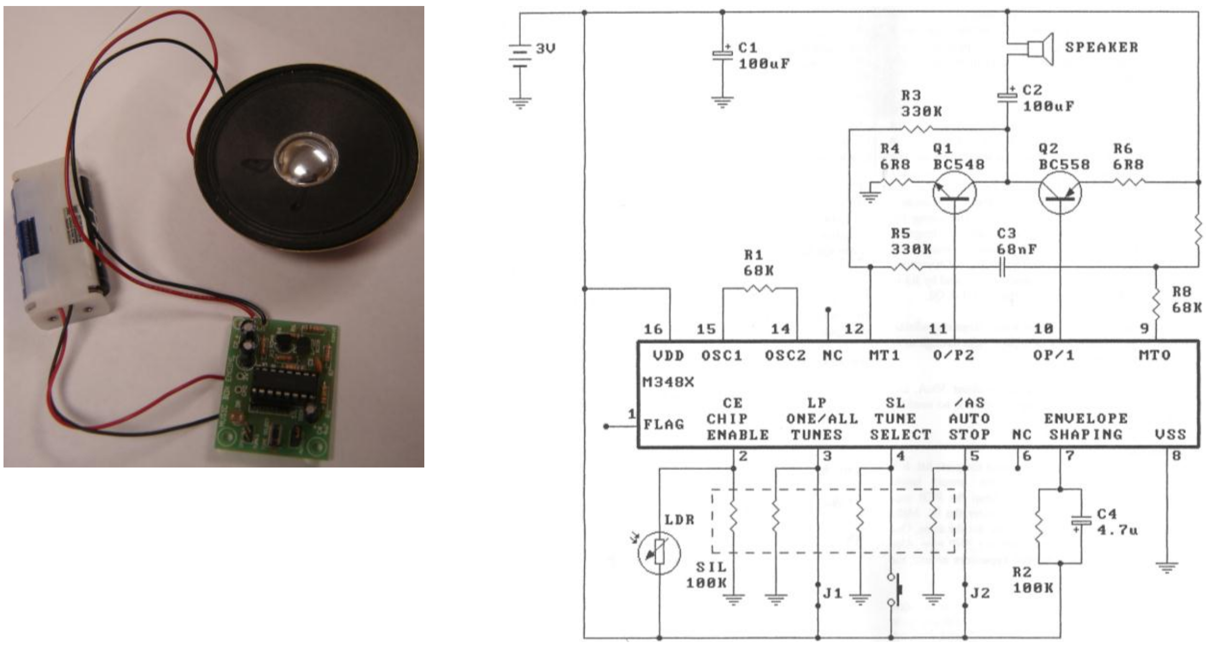


Figure 2: Pictorial view of the assembled music-engine printed circuit board (left) and the associated circuit schematic (right).

Project #3
In this project, students design, prototype, and test a 40 kHz infrared wireless remote controller. Preliminary design concepts are discussed in class, and then students complete the guided design process. First, the infrared transmit circuit is built and tested using a 555 timer IC and two infrared emitting diodes. Next, the receiver circuit is designed using a 40 kHz infrared receiver IC. The latch circuit for the receiver is designed using a D flip-flop, followed by a transistor current amplification circuit to drive the output LED. The complete circuit schematic of the wireless infrared remote controller is shown in Figure 3. Debugging and testing of the circuit is conducted via digital oscilloscopes available in the laboratory. Performance of student designed remote controllers is tested under various orientation and distance conditions. Through this experience, students are exposed to design, implementation, debugging, and testing phases of an engineering project. Students also get familiarized with typical laboratory test and measurement instruments while appreciating the hands-on nature of EET courses.

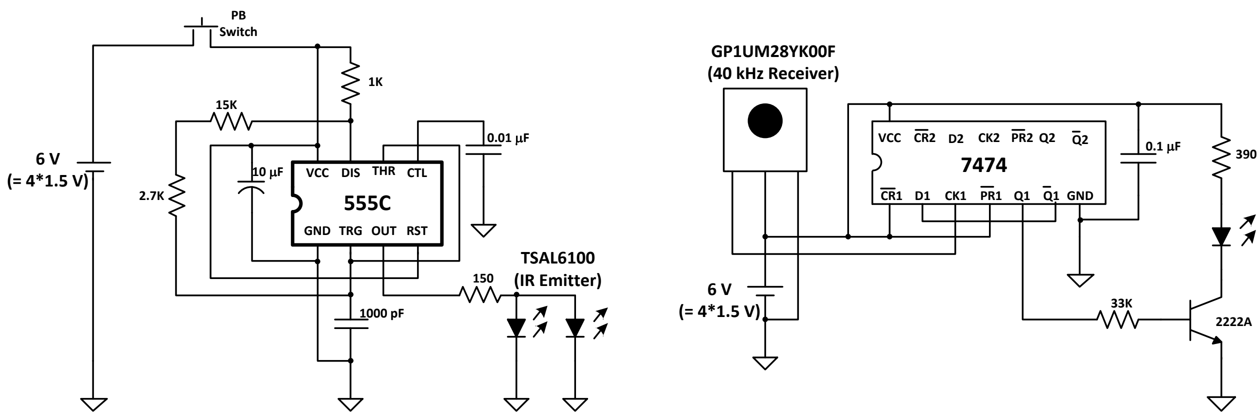


Figure 3: Circuit schematic of the 40 kHz wireless remote controller.

Project #4

In this construction project students build a bridge from spaghetti and glue/epoxy. The general objective is to construct a bridge that will carry the heaviest load while meeting the specifications such as span length, minimum width and maximum elevation of the deck, loading platform attachment, maximum vertical depth, and maximum mass of the bridge. Performance of the bridge is measured by an index defined as the ratio of maximum load carrying capacity to mass of the bridge. The maximum allowed mass of the bridge for this project is typically set at 300 g. The spaghetti bridge project was designed around the bridge design project[15] of the "What is Engineering?" course of Johns Hopkins University (JHU). Student groups in our course are given two chances to design and test their bridge with the better of the two counted as the final score. During the design process, students are encouraged to use easily available simulation packages such as JHU's Bridge Designer[15] and the West Point Bridge Designer[16]. A sample student-designed bridge, the bridge loading capacity test setup, and JHU's Bridge Designer user interface window are shown in Figures 4, 5, and 6, respectively. Using the software packages, students are able to visualize compressive and tensile forces in various members of the structure and are able to accordingly adjust the cross-sectional area of various members. This project is completed by students outside of regular class hours; however, bridge testing is carried out in class. The friendly competition among student groups creates an enjoyable experience for most students. By participating in this project, students gain an understanding of engineering design practices as well as the importance of teamwork and time management.

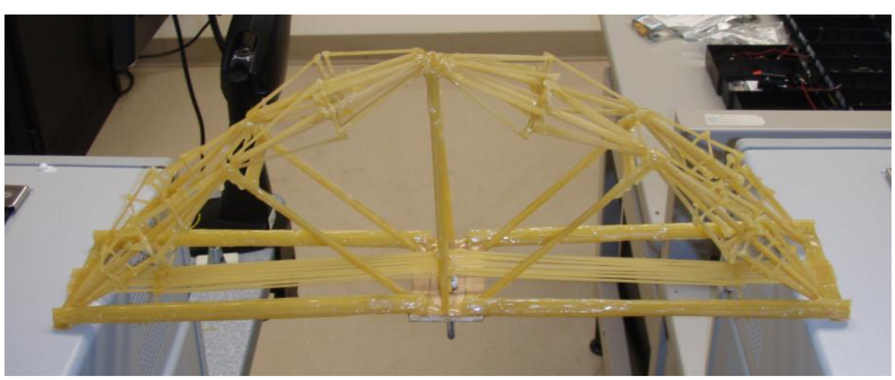


Figure 4: A sample student-designed spaghetti bridge.

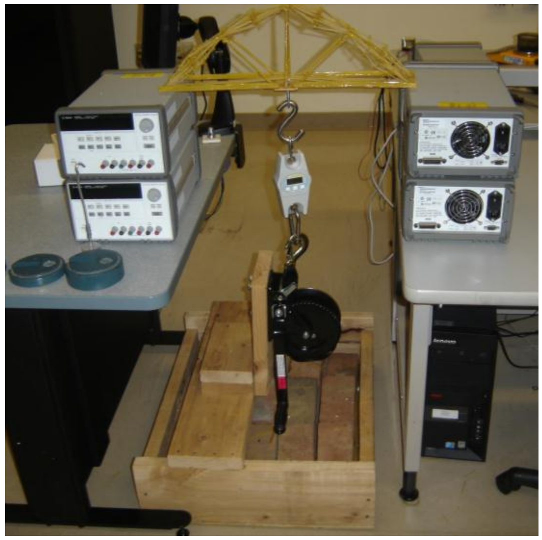


Figure 5: Pictorial view of the spaghetti bridge test setup.

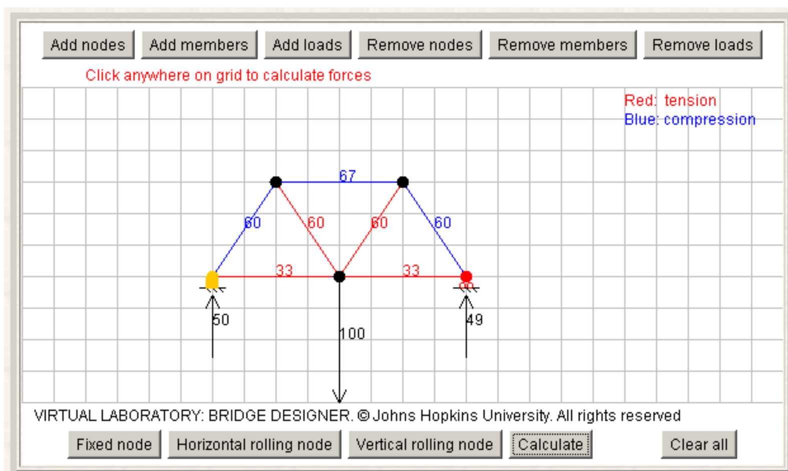


Figure 6: JHU's Bridge Designer user interface window.

Course Assessment

In addition to course-embedded direct assessment, indirect assessment of course objectives and associated student outcomes was conducted. Student responses are summarized in Tables II and III for course objectives and student outcomes, respectively.

Table II: Student Assessment of Course Objectives

Course Objective	(Excellent + Good) responses based on student survey
Developing mathematical and problem solving skills for engineering analysis	80%
Exposure to real-world engineering	93%
Hands-on construction and testing of simple electrical circuits and mechanical structures	73%

Table III: Student Assessment of Student Outcomes

Student Outcome		(Excellent + Good) responses based on student survey
a	Your ability to select and apply the knowledge, techniques, and skills of the discipline to electrical circuits, 1-D and 2-D motion, and engineering statics applications	73%
b	Your ability to select and apply mathematics and physics concepts and principles to solving engineering problems	68%
e	Your ability to function effectively as a team member or leader	73%
f	Your ability to identify, analyze, and solve applied engineering problems	53%
h	Your understanding of the need for engaging in self-directed continuing professional development	73%
k	Your commitment to quality, timeliness, and continuous improvement	73%

According to student responses, it can be stated that the course is able to meet its objectives of problem solving skill development and exposure to real world engineering. In the area of hands-on design experience, there is a need for improvement especially in regard to the level of guidance provided outside of class hours. Students' perception of outcomes is generally acceptable for a first-semester course. It can however be clearly seen in Table II that the area needing more attention in teaching is the use of math and physics concepts in solving engineering problems. However, it is to be noted that students get progressively comfortable solving engineering problems via their experiences in subsequent EET courses with strong emphasis on engineering concepts and applications.

A majority of students find this course to be relatively hard yet appreciate its emphasis on problem solving, a skill highly useful for succeeding in subsequent math, science, and EET courses. This sentiment is corroborated by students, 84% of them answered to "Ability to apply course material to improve problem solving skills" as *very high* or *high* at the university-level end-of-semester faculty and course evaluation. Additionally, anonymous qualitative end-of-semester feedback from students is sought and used as an input to the action item generation process for next offering of the course. Positive feedbacks as well as suggestions for improvement as provided by students are listed below.

- ✓ *Keep the problem solving and hands-on project components of the course as is*
- ✓ *Enjoyed team projects the most; add a couple of more mini projects*
- ✓ *Hard but very useful course*
- ✓ *Invited speakers and the field trip were excellent*
- ✓ *Open lab hours is appreciated*
- ➢ *For the bridge construction, replace the epoxy with white glue*
- ➢ *Spend a few minutes going over circuit board soldering technique*
- ➢ *Do not assume that students are familiar with all the math concepts used in class; spend a couple of classes reviewing algebra, geometry, and trigonometry learned in high school*
- ➢ *Add one hour a week problem session in the evening in addition to the scheduled tutoring hours*
- ➢ *Go slow the first few weeks of semester to help students get used to the fast pace of this course*

Summary

A problem-solving and project based introduction to engineering technology course suitable for freshmen students at our university is presented. Strong emphasis is provided on building students' quantitative problem solving skillset using mathematics and physics concepts. The goal is to let students academically grow in a rigorous course setting while improving their problem solving skill to help them succeed in future math, science, and engineering technology courses. This is complemented by hands-on engineering project opportunities as well as orientation to college life and engineering profession and industry. Students generally find this course demanding, however, by the end of semester most of them appreciate their experience in the course. Course-embedded direct and indirect student assessment data confirm that the main objectives of the course presented herein are met.

Bibliography

1. J. Choi, W. Grebski, and K. Dudeck, "The Development of Teaching Materials for an Introductory Course in Electrical and Mechanical Engineering Technology," Proc. ASEE Annual Conf., 2009.
2. G. Ma, "Innovation Teaching Technique in Introduction to Engineering Technology Course," Proc. World Congress on Engineering and Computer Science, Vol. 1, 2010.
3. S. Ahuja and A. Ross, "Introduction to Engineering Technology: VSU's New Approach," Proc. ASEE Southeast Section Conf., 2005.
4. S. Ahuja, "Math Remediation in a First Semester Engineering Technology Course," Proc. ASEE Southeast Section Conf., 2006.
5. P. Goeser, XC. Coates, and W. Johnson, "The Role of an Introduction to Engineering Course on Retention," Proc. ASEE Southeast Section Conf., 2003.
6. Criteria for Accrediting Engineering Technology Programs, 2012-13 Accreditation Cycle, ABET, http://www.abet.org/uploadedFiles/Accreditation/Accreditation_Process/Accreditation_Documents/Current/tac-criteria-2012-2013.pdf.
7. Eide, Jenison, Northup, and Mickelson, "Engineering Fundamentals and Problem Solving," 6th edition, McGraw-Hill, 2012, ISBN: 9780073534916.
8. Oakes, Leone, and Gunn, "Engineering Your Future," 7th edition, Oxford University Press, 2012, ISBN: 9780199797561.
9. Stephen, Bowman, Park, Sill, and Ohland, "Thinking Like an Engineer," Pearson Prentice Hall, 2011, ISBN: 9780136064428.
10. K. D. Hagen, "Introduction to Engineering Analysis," 3rd edition, Pearson Prentice Hall, 2009, ISBN: 9780136017721.
11. Pond and Rankinen, "Introduction to Engineering Technology," 7th edition, Pearson Prentice Hall, 2009, ISBN: 9780135154304.
12. S. Moaveni, "Engineering Fundamentals: An Introduction to Engineering," 4th edition, Cengage Learning, 2011, ISBN: 9781439062081.
13. ESource: The Prentice Hall Engineering Source, http://www.pearsonlearningsolutions.com/custom-library/esource.
14. Bedford and Fowler, "Engineering Mechanics: Statics," 5th edition, Pearson Prentice Hall, 2008, ISBN: 9780136129158.
15. Johns Hopkins University, Spaghetti bridge competition rules (http://www.jhu.edu/virtlab/spaghetti-bridge/) and simulation program (http://www.jhu.edu/virtlab/bridge/bridge.htm).
16. West Point Bridge Design Contest, http://bridgecontest.usma.edu/index.htm.

Appendix A: Student Assessment of Course Objectives and Outcomes

ENGTECH-101: Introduction to Engineering Technology

Fall-2011

Please **circle** the most appropriate answer to the following questions based on your experience in the course.

[E= Excellent, G= Good, S= Satisfactory, U=Unsatisfactory]

Objectives:

1. Your development of mathematical and problem solving skills for engineering analysis
   E G S U

2. Your exposure to real-world engineering
   E G S U

3. Your hands-on ability to construct and troubleshoot simple electrical circuits
   E G S U

Outcomes:

a. Your ability to select and apply the knowledge, techniques, and skills of the discipline to electrical circuits, 1-D and 2-D motion, and engineering statics applications
   E G S U

b. Your ability to select and apply mathematics and physics concepts and principles to solving engineering problems
   E G S U

e. Your ability to function effectively as a member or leader on a team
   E G S U

f. Your ability to identify, analyze, and solve applied engineering problems
   E G S U

h. Your understanding of the need for engaging in self-directed continuing professional development
   E G S U

k. Your commitment to quality, timeliness, and continuous improvement
   E G S U

Appendix B: Teamwork Evaluation Rubric

ENGTECH-101: Introduction to Engineering Technology

Instructor: ____________________

Student Team Members: ____

Project Title: ____

Semester: _____________ Date: __________________

	Accomplished (10)	**Competent (8)**	**Developing (6)**	**Beginning (4)**	**Performance**
Participating (25%): The instructor observed each student contributing to the project	Almost all of the time	Most of the time	Some of the time	Very few times	
Persuading (25%): The instructor observed the students exchanging, defending, and rethinking ideas	Almost all of the time	Most of the time	Some of the time	Very few times	
Questioning (25%): The instructor observed the students interacting, discussing, and posing questions to members of the team	Almost all of the time	Most of the time	Some of the time	Very few times	
Sharing (25%): The instructor observed the students offering ideas and reporting their findings to each other	Almost all of the time	Most of the time	Some of the time	Very few times	
Weighted Total Grade (MAX of 10)					

Instructor Comments: