From Undecided to Committed Engineering Student Through a T-Shaped Introductory Course Model

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***Abstract* - The introductory engineering course at Bucknell University is required for all entering first-year engineering students, averaging 185 students each year. Of those, approximately half are enrolled in the College of Engineering, but have not yet declared a specific engineering major. The introductory course has been structured to provide all engineering students with a "T-shaped" first experience in engineering: breadth of exposure to the engineering profession, engineering design, and the disciplines (the crossbar of the T), and depth in multiple engineering disciplines (the stem of the T). Nine faculty teach in the course, with representation from all engineering degree programs at Bucknell. End-of-semester evaluations and subsequent retention data indicate success in introducing the engineering profession and disciplines to first-year students, and in providing an appropriate foundation for subsequent coursework.**

Index Terms – Introductory engineering course, T-shaped educational goal, design project, disciplinary seminars.

INTRODUCTION

A common introductory engineering course, taken by all first-year engineering students in their first semester, can be a critically-important primary educational experience. Such a course can provide all engineering students at an institution with a common broad knowledge base about:

- engineering as a profession, and the engineering disciplines,
- professional ethics,
- the engineering design process: the melding of creativity and innovation with goal-oriented problem-solving and responsibility through design criteria and constraints, and the essential roles of customers or clients in that process,
- the value of multi-disciplinary teams in which individual expertise, and self-interest, and the team's project goals offer both opportunity and challenge,
- the importance of work ethic and accountability, and
- the potential for, and expectation of, advancing the human endeavor.

The introductory course should address a carefully-defined set of learning outcomes in ways that are internalized by students to the degree that they carry forward throughout their subsequent educational experiences. Without such a course as the students' first informed entry into the engineering profession, student perspective in the early years is typically limited by educational programs (necessarily) consisting predominantly of math, natural science, and engineering science courses in which the focus is on the solution of numerical problems carefully defined and limited in scope, the educational equivalent of tunnel vision in which creativity, innovation, and the needs of the customer or client, and society, fall from view.

A T-SHAPED FIRST COURSE IN ENGINEERING

The College of Engineering at Bucknell University offers B. S. degrees in biomedical, chemical, civil, computer engineering, computer science and engineering, electrical engineering, environmental engineering, and mechanical engineering. The engineering college enrolls approximately 185 first-year engineering students annually. Of those, about 60 percent applied to and were admitted into a discipline-specific engineering degree program; the remaining 40 percent were admitted into the College of Engineering, but without yet declaring a specific engineering major.

All entering engineering students are required to enroll in an introductory engineering course, ENGR 100 Exploring Engineering, in their first semester, along with calculus, physics, and a writing-intensive elective course. The educational goals of the course are listed above. At the conclusion of the course, students possess an initial perspective of the engineering profession and its disciplines, and the process, priorities and intricacies of engineering design that serves as context for subsequent coursework within their degree programs, and the selection of an engineering major as an informed choice is then possible.

To achieve these goals, the course has been structured to provide a T-shaped educational experience offering both breadth (the bar of the T), and depth (the stem of the T). Typically, nine engineering faculty teach in the course, representing all engineering departments in the college, and eight to ten course mentors (second-year engineering students) participate as both teaching assistants and mentors.

Educational Breadth

Educational breadth is the focus of three segments of the course spanning the full length of the semester. In the first segment, approximately two weeks in length, students are introduced to engineering (*i.e. the profession that creates what does not exist in nature for the benefit of humankind),* the concept of a profession, the various engineering disciplines, and the engineering design process. Engineering design is defined as:

> *A creative yet structured decision-making process (often iterative), in which knowledge is applied to convert resources to optimally achieve an objective: to solve a problem, to create something to fill a need, or a desire.*

The design process consists of ten steps, normally executed in sequence but often with iteration:

1. Identify the problem
2. Research and gather data
3. Establish design goals, criteria, and constraints
4. Identify potential alternative solutions
5. Evaluate potential alternative solutions
6. Develop and test models
7. Select the best alternative
8. Communicate and specify for implementation
9. Implement and/or commercialize
10. Perform post-implementation assessment

Students are formed into teams, given an engineering design problem (provide a reliable potable water supply to a mountaintop village in an underdeveloped country), and asked to complete as an assignment the first five steps of the process using decision matrices to evaluate their alternative solutions.

The second segment consists of a week-long introduction to professional ethics. This segment of the course has two objectives: provide students with an understanding of specific expectations for professional conduct; and provide opportunities for students to grapple with "ethical dilemmas," situations in which all expectations cannot be met regardless of an individual's course of action.

This segment starts with a discussion of morality and social responsibility, then moves to personal and professional ethics and the National Society of Professional Engineers (NSPE) Code of Ethics [1]. The segment includes a detailed discussion of a complex event with multiple ethical dilemmas (the space shuttle Challenger disaster is an example), conducted in small groups facilitated by a member of the course faculty. The segment concludes with an assignment in which the students are required to analyze an ethical case study drawn from the NSPE Ethics Review Board cases and selected to be challenging, but at the same time offering a series of ethical conflicts that students can readily envision themselves having to face in their professional lives. Many engineering faculty across the country agree from hard-earned experience that teaching personal and professional ethics is particularly challenging and more often than not results in only modest success; that is true at Bucknell as well. But many of the most significant engineering (and commercial) failures were rooted in ill-considered decisions that could have been avoided if they had been viewed through the lens of professional ethics; an early awareness of this framework for professional practice is essential.

Over the past two years, we have found that case studies can offer a level of realism that helps motivate students to internalize the concepts and applications, but the cases must be selected carefully to avoid those with trivial outcomes, situations that are so complex that essentially any course of action could be defended, or are so esoteric that students cannot relate to them.

Facilitated case study discussions in small groups can be effective, but the facilitator must be thoroughly prepared to lead the discussion, engage all students, and ensure the discussion produces the desired take-away messages. Similarly, the students must be thoroughly prepared to engage in the discussion; we have found that a short pre-discussion written test has been helpful in ensuring most students have carefully read and thought about the case study to be discussed.

The final segment involves a comprehensive team-based design-build project that is introduced to the students during one week in late October, becomes the sole focus of the course beginning in mid-November, and concludes in a public exposition at the end of the semester attended by elementary education majors at Bucknell, local school teachers, scout leaders, and groups of 10-year-old children, often with parents. At the conclusion of the exposition, all projects are expected to be given away to adult attendees along with supporting documentation on use of the projects in an educational setting and the materials and fabrication methods employed in constructing the projects.

The project employs real customers, objectives, constraints, and budget, and requires the students to conceptualize, design and construct a working full-scale device for use in grade-school classes and Cub Scout groups to demonstrate scientific and engineering principles. The students are placed into teams of four, and each team executes the project with guidance from their customers and faculty adviser; the result is 50 different project products. The project requires students to effectively collaborate in a team setting, apply creative thinking to ambiguous problems, often persist through failure, and interact with both primary clients (teachers and scout leaders) and secondary customers (10-year-old children).

The goals of the project are challenging. For most students, it is the first time they need to meet with and satisfy a customer whose guidance and preferences may be vague, inconsistent, or in conflict with the students' initial conceptualization of the project and design outcome. Further, they need to maximize realization of multiple design criteria, meet multiple design constraints (including a real budget and significant time and fabrication limitations), and build a real (physical) device that works well, works repeatedly, intrigues 10-year-olds and will stand up to repeated enthusiastic uses by them, and is designed and documented well enough to enable teachers and scout leaders without any engineering background and relatively little scientific background to use the device to help youngsters learn selected engineering or scientific principles.

Disciplinary Depth

Nine seminars are offered at three different intervals during the semester, each three weeks in length and focused in a specific engineering discipline. The seminars provide students with an introduction to that discipline in some depth with an incorporated design experience. They are also intended to expose students to the educational environment and expectations they would experience in subsequent engineering courses in that discipline. Each student submits their rank-ordered preferences of seminars, and is subsequently enrolled in three different seminars. As a result, each student must take seminars in at least two different engineering disciplines. Typically, each student gets his or her first choice of seminar, and most get their second choice as well. The seminars average 25 students in each seminar offering.

Each seminar has the following components and deliverables:

- Lectures and laboratories that build knowledge and specific skills in the discipline;
- At least four graded homework assignments;
- Some graded lab documentation – consisting of any combination of pre-labs, formal lab reports, informal lab data reports, etc.;
- An overarching design project conducted by teams of two or three students;
- A written report on the project;
- A final examination (no less than 50 percent of the final seminar grade is to be based on individual work).

Representative abstracts of seminars included in the 2012 offering of the course include:

Better, Stronger, Faster: Engineering Athletics – Department of Chemical Engineering

Most athletic activity requires proper footwear to enhance performance and to protect the athlete from unnecessary injury. Improvements in design, performance and comfort are continually sought. In this seminar, we will examine the impact of engineering on the sneaker. Students will design and conduct experiments in search of the "best" design for sneaker materials, and develop a method to economically produce that material. The technical material covered will include an introduction to materials science, polymer science, and manufacturing engineering.

Engineering and Drug Delivery - Department of Biomedical Engineering

When you take a Tylenol, where does it go? How long does it take to dissolve in your stomach and what makes it dissolve? How does it get to your sore knee? In this seminar, we will explore some of the fundamental concepts behind drug delivery, blood flow and the overall transport of chemicals in the human body. To do this, we will utilize some hands-on dissolution and fluid flow experiments. The design process and modeling methods will also be introduced to help analyze your lab data and relevant assigned problems. At the end, your lab team will design an experiment to study the compound effects of dissolution and fluid flow principles covered in class.

Sense, Compute, Control –Department of Electrical Engineering

The most common way of moving energy and information in our lives is with electrons. We use electronics to glean information about the real world around us, which can be a simple as whether a switch is closed or as complex as global climate data. This information is then combined, processed, and transformed by computing circuits. The final results are then communicated back to us or used to control some aspect of our environment. Behind it all is a massive system for generating, distributing, and monitoring electrical energy; a system that works so well that we often take it for granted. Students in this seminar will explore three of the important themes from electrical and computer engineering by designing and constructing an intelligent monitoring system. You will begin by creating circuits that sense something in the environment, such as temperature or light. The information from these sensors will then be processed by simple computing logic. Finally, the computed results will be used to control devices that communicate information or affect the environment, such as lights, fans, and motors.

The Power of the Sun: Solar Energy and Sustainability – Department of Mechanical Engineering

In 2011 the United States consumed 97.5 quadrillion Btu of energy. That's 97,500,000,000,000,000 Btu. Most of that energy came from non-renewable sources, including coal, petroleum, natural gas and nuclear energy. Only 9% came from renewable sources. In this seminar we will discuss energy, both how it is generated and how it is consumed. We will specifically focus on solar energy by investigating the different methods available to harvest energy from the sun, and the advantages and disadvantages of each method. The seminar will include a project to design and build a solar oven.

Gripped by Design – Department of Mechanical Engineering

Autonomous robots have gained increasing popularity in civilian and military applications and have been implemented in harsh environments including bomb defusal and industrial automation. Robots fall at the intersection of mechanical design and control. In this seminar, we will focus on the role of motion and forces in the design of a robotic gripping mechanism. To that end, students will obtain a whirlwind introduction to mechanism kinematics, rigid body statics, and mechanical component design. Students will work in teams to design, build, and test a robotic gripper to pick-and-place objects of various shapes and sizes. The grippers will be incorporated on a 3-DOF robotic arm, and the seminar will conclude with a competition between all teams.

The overview, objectives, and schedule of a typical three-week seminar, *Bridges: Function, Forces and Failures*, are given below:

Seminar Overview

This seminar will introduce the engineering design process through a focus on highway bridges. Students will learn how specific design requirements or criteria, and anticipated loads on a structure, are considered during bridge design. Included is an introduction to the analysis of internal forces produced by external loads, and how those internal forces result in stresses. The behavior of metals subjected to internal forces, both "static" and impact forces, will be studied as well. The seminar will include lectures, homework, lab experiments, a field trip, and a bridge design project. In that project, student teams will apply the engineering design process using educational bridge design software.

Seminar Objectives

By the end of the seminar, students will be able to:

1. Identify and sketch the various bridge types, and briefly describe how each type resists loads;
2. Identify the requirements (design criteria) used in the design of bridges;
3. Define and calculate internal forces caused by external loads in beams and trusses;
4. Define and calculate axial stresses in truss bars;
5. Differentiate between ductile and brittle metals and describe the primary mechanical properties (such as yield and ultimate strength);
6. Describe how temperature can influence the impact strength of certain metals;
7. Briefly describe the typical bridge design process and how hydrology, transportation planning, geotechnical analysis and structural analysis are critical elements of the design;
8. Apply the engineering design process to a bridge, resulting in the optimum design of a truss bridge using the bridge design software provided.

Seminar Schedule

Lecture 1	Seminar introduction; bridge types
Lecture 2	Introduction to loads, forces, and free body diagrams
Lecture 3	Internal forces and free body diagrams
Lecture 4	Types of stresses and strains
Lecture 5	Mechanical properties, strengths of metals
Lecture 6	Flexural analysis and stress
Lab 1	Metals testing: tension, impact
Lecture 7	Introduction to bridge design and project
Lecture 8	Bridge project, design software demonstration
Lecture 9	Column behavior: flexural buckling
Lab 2	Field trip, girder and truss bridges
Lecture 10	Seminar final examination

The seminar project involves the use of software to assist in the detailed design (truss member selection) of a deck truss bridge using at least four span-to-depth ratios to determine the minimum-cost span-to-depth ratio. The project assignment documentation is given below:

Purposes and Overview

This seminar project focuses on the design of a two-lane highway bridge. The project will help you learn about and apply the engineering design process, learn some of the fundamentals of engineering mechanics that underlie the design of structures, and learn some of the challenges and benefits of teamwork. Your three-person design team will use the 2012 West Point Bridge Design (WPBD) software to design a safe and cost-effective truss bridge to span 44 meters (144 feet) over a small river and submit a design report. In the design process, you will seek to optimize the design by varying the geometry of the trusses that support the bridge deck as well as the individual truss member types and sizes.

Background

The initial design of a bridge involves the determination of its alignment, size, and type. The criteria used in that process include the design highway capacity that determines the number of traffic lanes, maximum roadway grades, minimum clearance required under the bridge, and minimum horizontal clearance or bridge length. Bridges are considerably more expensive per foot of length than the roadway, so the initial design will typically seek to minimize the length of the bridge.

In this project, we will assume that the initial design has been completed, resulting in a two-lane single-span bridge with a length of 44 meters and a deck elevation 24 meters above the flood water level. Further, it has been determined that a truss (actually, a pair of trusses, one on each side of the bridge deck) will be used to support the deck and span between the abutments (the foundations at each end of the bridge). There are two truss bridge types: a "through truss," in which the trusses are above the bridge deck, and a "deck truss," in which the deck rests on top of the trusses. Of the two, a deck truss is preferred (if there is sufficient clearance under the bridge to permit it), as it does not restrict the height or width of occasional oversize vehicles and is less likely to be exposed to deicing salts applied during winter weather. At this bridge site, there is lots of vertical clearance between the high water level and the bridge deck, so a deck truss system is to be used.

The cost of a truss bridge is influenced by a number of factors, such as the specific type or geometry of the truss selected, and the strength of the materials used for both the truss and the concrete deck it supports. Two other factors, however, are generally the most important in producing an optimum (minimum cost) truss bridge design:

1. The span-to-depth ratio of the truss. Very shallow trusses require very heavy top and bottom chord members, while very deep trusses have light top and bottom chord members but must have long vertical and diagonal truss members. As a result, there will be an optimum (least cost) span-to-depth ratio for the truss that lies somewhere between those two extremes.
2. The choice of truss member types. Trusses are comprised of two types of truss members: compression members (bars loaded in compression, like a column), and tension members (bars being pulled or stretched), and any truss acting like a beam will have both tension and compression members in it. Of the two, tension members are the most efficient, as they will fail only through the failure of the material itself if overloaded, i.e. the stress in the tension member at failure will equal the failure stress (strength) of the material. Compression members, unless *very* short and stocky, will fail by **buckling** when overloaded, at a stress less than (and often a *lot* less than) the material's failure stress. Compression members can be made more efficient if the cross-section configuration has more of the material located away from the center of the cross-section. As a result, round or square hollow tubes are better choices for compression members: even though they are a little more expensive to produce than solid round or square bars, they are much better at resisting buckling so less material is needed to resist a given load, and their overall cost is therefore lower. For tension members, the shape of the cross-section doesn't influence the strength of the member, so the least-expensive-to-produce shape is the best choice: round or square solid bars.

Specific Design Objective

You are seeking the least-cost truss depth for the bridge using the design parameters above. **Design at least four optimized bridges** using a different depth of the deck truss for each design, ranging from a depth of 3 meters (a span-to-depth ratio of about 15:1) to a depth of 8 meters (a span-to-depth ratio of about 5:1). One of the depths must be three meters, and a second must be either seven or eight meters, to cover most of that range. For each design, the optimization process will involve selecting the smallest square hollow tube or square solid bar for each truss member that still results in a bridge that can carry the design truck load. The software will let you load-test your design to determine which members can be made smaller (smaller cross section), and which members aren't large enough. The software will also calculate the total cost of each of your optimum bridge designs, and you will be able to identify the design with the optimum truss depth and its cost.

Report your results (member types and sizes and total bridge cost) for each span-to-depth ratio, plot total cost vs. truss depth, and identify the minimum-cost depth.

EVALUATION RESULTS

Student feedback is obtained at the end of the semester through anonymous course evaluations. Likert scales are used for numerical responses, with 5 being "strongly agree" and 1 being "strongly disagree." The following response averages were obtained from questions in the most recent offering of the course, fall semester 2012:

This course has improved my general understanding of what engineering is.	4.57
After taking this course, I have a better understanding of the relationships between society and engineering.	4.57
This course has improved my understanding of the ethical and professional responsibilities of engineers.	4.54
My understanding of differences among specific engineering disciplines has been improved by this course.	4.42
The course confirmed or influenced my decision of major.	4.26
My interest in engineering has been stimulated by this course.	*4.36*

Projects in this course gave me an opportunity to practice the engineering design process	*4.46*
The seminars were a valuable component of the course	*4.44*
For me, the overall value of taking this course was high.	4.37

CONCLUDING REMARKS

To support a course structure providing effective educational opportunities of both professional breadth and disciplinary depth to approximately 200 first-year students, nine engineering faculty and 10 course mentors are directly involved in the course scheduled with three separate all-student segments and nine three-week seminars offered multiple times at intervals during the semester. At varying times during the semester, the course makes use of a large lecture hall, eight standard classrooms, discipline-specific laboratories, the college machine shop, and an exposition hall. The logistical challenges of this structure are significant, and one of the nine faculty is designated as the course coordinator with a one-course release for that role. It is important that the course organization appears to be relatively seamless from the students' perspective so as not to detract, or distract, from the educational experiences within.

With nine faculty offering seminars, clear expectations for each seminar's objectives, deliverables, and structure are particularly important. Assessment consistency is also important, as students enroll in only three of the nine seminars offered. A target final seminar average is agreed upon, and variations in those averages are reviewed by the course coordinator and by the all faculty in the course.

Of the nine faculty in the course, five lead the professional ethics case study discussions, and each advise ten student groups in the final design/build project, and careful preparation and consensus-building are essential to ensure educational experiences that are of consistently high quality for all students.

The T-shaped structure of the course provides broad exposure to the engineering profession, the disciplines, engineering design, and professional ethics while also providing opportunities to experience three engineering disciplines or sub-disciplines in some depth and gain experience in the level of workload and intellectual challenge the students will experience in subsequent engineering courses.

REFERENCES

1. National Society of Professional Engineers, *NSPE Code of Ethics for Engineers*, Alexandra, VA, 2013